BOARD OF EDUCATION SCIENCE MUSEUM

# HANDBOOK OF THE COLLECTIONS ILLUSTRATING AERONAUTICS—III
# THE PROPULSION OF AIRCRAFT

A BRIEF OUTLINE OF THE HISTORY AND DEVELOPMENT OF THE AERO-ENGINE AND THE AIRSCREW WITH REFERENCE TO THE NATIONAL AERONAUTICAL COLLECTION, AND A CATALOGUE OF THE EXHIBITS

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# LIST OF ILLUSTRATIONS

# INTRODUCTION

ADEQUATE propulsion is as necessary to the proper functioning of aircraft as it is in any means for transport. Moreover, in the case of heavier-than-air craft, the propulsive force is essential for the craft to remain in the air, as, without its induced forward motion, it must descend to earth. For this reason, propulsion equal to all necessity becomes a factor of supreme importance and the engine must be considered as the heart of the machine, without which it cannot function.

The earliest successful attempts to apply a motive force to aircraft in full scale experiment were made in connection with the propulsion of dirigible balloons during the nineteenth century. It was not until the beginning of the twentieth century that the internal combustion engine reached that stage of development which permitted its application to heavier-than-air craft and rendered the success of the power-driven aeroplane possible. The first controlled and sustained flight by man in a power-driven aeroplane took place on December 17, 1903, and that notable achievement marks the beginning of a period of steady progress in the perfection of the light internal combustion engine and the airscrew, for the purpose both of aeroplane and of airship propulsion.

The determining factor of an efficient aero-engine is maximum power for minimum weight compatible with a high degree of reliability in flight and a form which can be included readily in the design of an aircraft. The high standard which has been reached to-day may be judged from the recent performances of the airship Graf Zeppelin on her world-flight, and the accomplishment by the Supermarine Rolls-Royce Seaplane S.6 of a speed of no less than 357·7 miles an hour—performances which testify on the one hand to the reliability, and on the other to the power output of modern aero-engines.

*  *  *  *

This publication is intended to serve as an introduction to the study of the history and development of the aero-engine and the airscrew with special reference to that section of the National Aeronautical Collection at the Science Museum which has been formed to illustrate this branch of engineering, and an endeavour has been made in the historical and technical survey to refer to all the salient features of design from the beginning up to the present day. The published works on aeronautical engineering supply a considerable amount of data which has necessarily to be excluded from what is merely a brief survey of the subject. A list of some of these works which are available in the Science Museum Library and have been consulted, will be found

# PREFACE

THE National Collections in the Science Museum are so arranged as to illustrate the development of physical science and to show the ways in which it has been applied to various branches of industry. In each group the more important stages of development are represented by selected objects, and others taken from the practice of to-day complete the history. While the historical series changes but little, the objects in the current series are continually being replaced from time to time by later examples.

Whenever possible exhibits are arranged so as to be set in motion by visitors, and many of them are sectioned and opened up so that the inner construction and working parts can be studied.

The creation of a Museum of Science was proposed by the Prince Consort after the Great Exhibition in 1851, and in 1857 collections illustrating foods, animal products, examples of structures and building materials, and educational apparatus, were brought together and placed on exhibition in South Kensington.

The following additions, besides many other smaller ones, were subsequently made—the collection of machinery formed by the Commissioners of Patents in 1883, the Maudslay Collection of machine tools and marine engine models in 1900, and the Bennet Woodcroft Collection of engine models and portraits in 1903.

The Aeronautical Collection is of comparatively recent origin, but it already contains many objects of great historical interest as well as a large number of the most recent types, the whole forming a very comprehensive representation of the growth and present standing of practical aviation.

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at the end of this book. Information regarding current aero-engine design and practice has been extracted mainly from the relevant technical journals which are included also in this list. The reader is referred to the Handbook of the Collections Illustrating Heavier-than-air Craft—to which this publication is supplementary—for an outline of the history and development of mechanical flight.

The National Aeronautical Collection includes examples of over eighty aero-engines which illustrate the development up to the present day. Many engines are sectioned in order that the internal mechanism may be studied. In some cases they are shown in operation.

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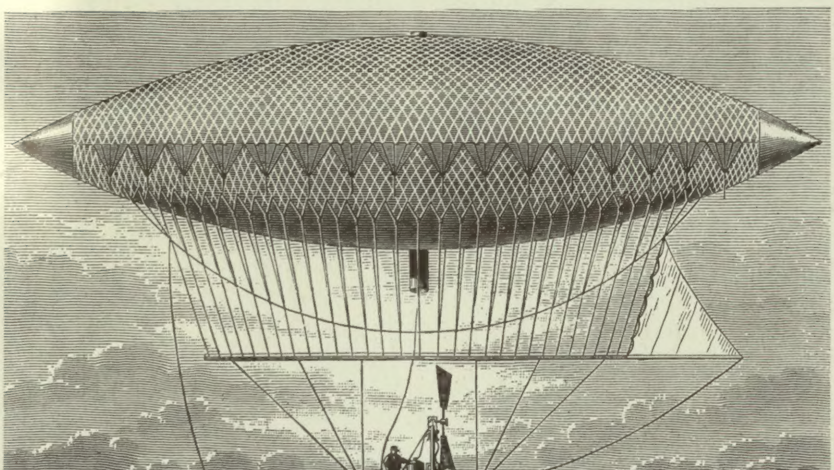
PLATE I


Lunardi's Method of Oar Propulsion, 1784.



Giffard's Airscrew Propulsion, 1852.

# HISTORICAL SURVEY

## I. Early Proposals for the Propulsion of Aircraft

Probably the earliest reasoned speculations in regard to propulsion in the air may be attributed to Roger Bacon, who, in 1250, discussed in his "Secrets of Art and Nature," the moving of artificial wings to beat the air in the manner of a bird. The idea of sustentation and propulsion in the air by means of artificially flapped wings, which was inherent in all the early proposals for the accomplishment of mechanical flight, was considered in a truly scientific spirit by Leonardo da Vinci (1452–1519), and he designed several flying machines on that principle, but they are more of historic interest than practical value. He conceived also, in a crude form, the lifting screw, or helicopter, an invention of very considerable significance.

Another early record of a proposal for the propulsion of aircraft is that contained in Francesco Lana's conception of a "flying boat," described by him in 1670. This proposed vessel—which was intended to float in the air by virtue of the displacement of four large copper globes from which the air has been evacuated—was to be propelled by a sail and it was thus depicted in contemporary illustrations; the use of oars was also considered. The fallacy of the proposal to use sails for the propulsion of a vessel moving wholly in one element was so apparent that the more scientific speculators deliberated on the application of some motive force when the invention of the hot-air or Montgolfier balloon in 1782–3, and the hydrogen balloon in 1783, rendered ascent in the air possible. The use of animal power in the form of trained eagles, kites, and other birds was also considered. The desire to evolve a satisfactory means of propulsion for lighter-than-air craft resulted in various forms of mechanism being devised and tested for this purpose. Manually operated wings and oars were tried; notably by the French balloonist Jean-Pierre Blanchard, who in 1784 made use of oars consisting of light framework covered with silk. Subsequently, he is said to have employed a *moulinet*, or rotating fan—a device of some significance. In the same year, 1784, the balloonist Lunardi employed oars for the propulsion of a balloon over London (see Plate I). At a much later date (1834) a navigable balloon, "L'Aigle," constructed by the Comte de Lennox and Le Berrier, was provided with manually operated paddle-wheels supplemented by oars, but it did not meet with any marked success.

The possibility of propulsion by the reaction resulting from the emission of a jet of air or steam was considered and also the use of the explosive reaction of gunpowder fired in the form of a rocket—a method which has not yet been fully explored. In 1784 two Frenchmen,

Miolan and Janinet, constructed a Montgolfier balloon designed to be propelled by means of jets of hot air emitted from the balloon, but the project failed.

So numerous were the attempts made at this period to devise a satisfactory and efficient mechanism to apply manual or other power for the propulsion and navigation of balloons that it is not feasible to describe them in detail here ; it is sufficient to say that in no case did they prove really satisfactory.

The application of the screw as an air propeller, for propulsion in the horizontal plane, was first suggested by the French officer, General Meusnier, in 1784, and it solved the first part of the problem of propulsion. True progress may be said to date from its inception.

## *II. Introduction of the Airscrew*

It has already been noted that the lifting airscrew, or helicopter, was first conceived by Leonardo da Vinci, being described by him about the year 1500, and also that the balloonist Blanchard employed, in 1784, a form of rotating fan which must have been intended to function on this principle. The idea of the lifting airscrew was revived by the French mathematician Paucton, who published a treatise, " Théorie de la vis d'Archimede," 1768, in which he described a projected apparatus named the *Ptérophore* consisting of two airscrews, one for sustentation and the other for propulsion.

Probably the first practical experiments in regard to lifting airscrews were made in France by Lannoy, a naturalist, and Bienvenu, a mechanician, who together constructed a model apparatus consisting of two superposed airscrews about one foot in diameter each in the form of four feathers and so arranged at the top and bottom of a rod that they could be made to rotate in opposite directions by means of a cord which was unwound by the tension of a bow drawn taut in winding. This device was exhibited before the French Academy of Sciences in 1784, and it was stated that the airscrews were arranged so that : " the horizontal percussions of the air neutralized each other, and that the vertical percussions combine to raise the machine. It therefore rises and falls back afterward from its own weight." There is no evidence that the device was much further developed at that time.

The distinguished French General, Jean Baptiste Marie Meusnier (1754–93), is accorded the distinction of having first actually proposed the use of airscrews in a practical form for the propulsion of a balloon. In 1784 he prepared designs for the construction of an ellipsoidal balloon to be propelled by three " revolving oars," or airscrews, worked by manual power. The vessel was not built, owing to the prohibitive cost, but the design remains as the important record of the inception of the screw propeller as applied to aircraft.

The great pioneer of mechanical flight, Sir George Cayley (1774–1857), who made by far the most important contributions to the science

of aeronautics during the first half of the nineteenth century, is stated to have made his earliest experiments in 1796 with a Chinese or aerial top—a device which served to illustrate the principle of the lifting airscrew. Cayley, in the course of his researches, devoted much time to the consideration of means for the propulsion of aircraft, and he evolved designs both for lighter-than-air and heavier-than-air craft. It is significant that he repudiated the idea of support and propulsion in the air by means of wings worked by manual power, and that he concentrated on the application of the airscrew and the discovery of a suitable power unit in pursuance of his conviction that the whole problem of mechanical flight was, as he defined it, " to make a surface support a given weight by the application of power to the resistance of the air."

The airscrews proposed by Sir George Cayley as essential components in his designs for lighter-than-air and heavier-than-air craft, and depicted in contemporary illustrations, were of two distinct types: the one intended solely for propulsion in the horizontal plane and the other designed to obtain direct support in the air. The screws consisted generally of two or more blades set radially about a central axis to be rotated by steam or other power. His improved design for a navigable balloon (1837), to be inflated with hydrogen and driven by steam, shows double airscrews, each having five blades, and these screws were set upon outriggers. The other form of airscrew proposed by Cayley was, as previously stated, for lifting purposes and consisted of eight apparently flat blades set about a spindle which was to be rotated at an angle nearly approaching the vertical. His proposal for an " Aerial Carriage " (1843) included four of these lifting screws arranged in pairs to be rotated in opposite directions. Two small two-bladed airscrews were provided to obtain horizontal thrust for propulsion. It is unlikely that Cayley ever attempted to construct this machine as the question of a suitable prime mover remained unsolved.

In connection with the propulsion of aircraft he considered the type of steam engine recently invented by Boulton and Watt, and the crude form of internal combustion engine which had been experimented with at that time, and he seems, with his unfailing wisdom, to have had a preference for the latter. There is reason to believe that he anticipated the construction of the type of gas engine which was developed half a century later.

Subsequent to the outstanding work of Cayley, in the whole field of aeronautics, there were made, throughout the nineteenth century, innumerable speculations and experiments in regard to the design of aircraft and their propulsion. Of these the majority were concerned with the application of the airscrew primarily for support, and many proposals for the design of helicopters were advanced. Some of these proposed machines are described in detail under the heading of " Screws to Lift and Propel," in a valuable record published by Octave Chanute in 1894 and entitled *Progress in Flying Machines*.

Towards the close of the nineteenth century valuable research in

the design of airscrews was conducted on a scientific basis by Sir Hiram Maxim in England and by Professor Samuel Pierpoint Langley in America, and by others. This phase of the development of the airscrew followed the earliest applications of prime movers to aircraft and it will, in consequence, be dealt with at a later stage. It will be seen that the introduction of the airscrew, though as yet untried and undeveloped, rendered the application of power a feasible proposition and it remained to design and apply a suitable engine to the lighter-than-air craft already conceived, and to the heavier-than-air craft when that had been evolved.

## *III. The Earliest Aero-Engines*

[*Numerical references in the text refer not to the page, but to the serial numbers placed at the beginning of each object described in the Catalogue at the end of the book.*]

The consideration of a suitable prime mover for use in aircraft had occupied the minds of most of those who had speculated seriously in regard to human flight. Sir George Cayley, as already noted, gave deep thought to this question, being convinced that the development of a suitable engine was essential to progress. Though he formulated proposals for craft to be propelled by steam, he appears in his later writings to have shown a preference for the crude form of internal combustion engine utilizing gas, which was at that time being experimented with.

The disadvantages of the steam engine for aircraft propulsion—entailing as it did considerable weight and danger from fire—were fully realized, but, in default of any other prime mover being sufficiently developed to render its application feasible, steam was the only available power.

The earliest record of a steam engine actually being made for propelling aircraft in model form is that of the Englishman, William Samuel Henson (*b.* 1805), who, about 1840, began the construction of a light steam engine which was to weigh, with water and fuel, approximately 10 lb. This engine was intended for the propulsion of a model to illustrate Henson's very remarkable conception of an aeroplane, " The Aerial Steamer," which he had evolved. (See Handbook of the Collections Illustrating Heavier-than-air Craft.) It appears, however, that this model engine did not prove satisfactory, and in 1843, Henson having entered into collaboration with John Stringfellow (1799–1883), the construction of a suitable engine was given over to the latter. Stringfellow, who had previously been engaged on a light steam engine of his own, proceeded to construct an engine having a single direct-acting cylinder 1·5 in. diameter with 3-in. stroke designed to attain a speed of approximately 300 revolutions per minute (see Plate II). A great deal of time was spent in perfecting this engine (1). It seems the complete model was not tried until 1847, when experiments were made with it on Bala Down, two miles from Chard in

Somersetshire, and did not prove successful. Apparently the machine was unable to support itself for any distance and descended gradually after being launched. According to Stringfellow, this failure was not due to lack of power or insufficiency of supporting surface, but rather to the shrinkage of the silk which covered the wings, due to the moisture in the air, and caused a deformation of the surfaces. A description of this and other models, together with an account of the experiments, is contained in a pamphlet written by F. J. Stringfellow (son of John Stringfellow) under the title of " A few Remarks on what has been done with screw-propelled Aero-plane Machines from 1809 to 1892."

During the years 1847 and 1848 Stringfellow continued the work he had already begun—the perfecting of his light steam engine ; and he constructed a model aeroplane which be based largely on Henson's design. His perseverance resulted in an event of great importance in the history of mechanical flight—the achievement in 1848 of the first sustained flight with a power-driven model aeroplane. A description of the model, the greater part of which is still in existence, and the best account of the successful flights, are given in the pamphlet already mentioned, which was published by Stringfellow's son in 1892. The account states that the engine (see Plate II) drove " right and left screw propellers 16 in. in diameter, with four blades occupying three-quarters of the area of the circumference, set at an angle of 60 degrees." Also : " The cylinder of engine three-quarter inch diameter, length of stroke 2 in., bevel gear on crank-shaft giving three revolutions of propellers to one stroke of engine. The weight of entire model with water and fuel was under nine pounds."

In addition to the particulars of the engine given above it is interesting to note that it was horizontal and double acting ; that the boiler was made of thin copper with silver-soldered joints and consisted of inverted truncated cones arranged round and above the furnace. The cones were connected with a central steam drum above them and with water chambers below. The boiler was fired with a naphtha lamp. The power developed by the engine, and the thrust obtained, appear to have been quite adequate for sustained flight—in fact, a statement that the machine " gradually rose " indicates that there was a margin of power (2).

It appears that, after the successful accomplishment of model flight, Stringfellow rested on his achievement and did not recommence experimental work until the foundation of the Aeronautical Society of Great Britain in 1866 revived his interest and he set about the making of a triplane model for the Society's first aeronautical exhibition which was to be held at the Crystal Palace in 1868.

In addition to the triplane model Stringfellow exhibited a complete steam engine of about one-half horse-power, and a one horse-power boiler and firebox weighing about 40 lb. and capable of sustaining a pressure of 500 lb. per sq. in. The boiler was stated to generate steam up to 100 lb. pressure in five minutes, when the engine drove two

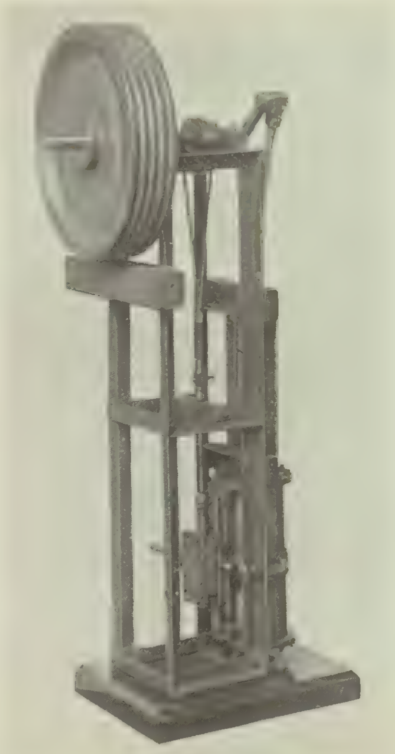
21-in. diameter propellers at 600 revolutions per minute. Owing to the danger from fire, no complete test of the model was permitted, but it is stated that, when attached to a line by a travelling pulley and allowed to run forward, it showed an evident tendency to support itself.

A prize of £100 was awarded to Stringfellow by the Aeronautical Society for the lightest engine in proportion to its power, the computation being made from the data concerning the half horse-power engine.

The first successful application of power to actual man-carrying aircraft was made by the Frenchman, Henri Giffard, in 1852, when he constructed an elongated balloon and suspended beneath it a car containing a small steam-engine arranged to drive a single airscrew (see Plate I). The engine was stated to develop 3 horse-power and it weighed about 350 lb. complete with boiler. Giffard succeeded in attaining a speed of about 6 miles an hour with this airship in calm weather, and he carried out some useful experiments. The power was insufficient to enable him to make a complete circle in a wind of any velocity, but he was able to perform some evolutions and "deviate from the direction of the wind with the assistance of his rudder"; thus demonstrating that a lighter-than-air vessel could be navigated by the application of an engine and airscrew and the necessary aerodynamic controls. The dirigible balloon, or airship, of Henri Giffard appears to be the only instance of a steam-engine being fitted to lighter-than-air craft, though in the light of modern development, the use of steam, in another manner, has again been contemplated. The inherent disadvantages of the early steam-engine were, of course, the excessive weight entailed by the carrying of fuel and water, etc., coupled with the considerable danger from fire.

The first application of the primitive internal combustion engine using gas as fuel was made in Germany by Paul Haenlein, who, in 1872, accomplished a speed of about 10 miles an hour with a balloon propelled by a Lenoir type of engine. This engine, which was said to have developed some 6 horse-power, utilized gas drawn from the balloon itself and, in consequence, the experiments could not be prolonged as the buoyancy of the balloon was decreased. The disadvantages of the internal combustion engine using gas as fuel was that it necessitated the carrying of a gas-producing plant or a large container for storage, either of which added considerably to the total weight.

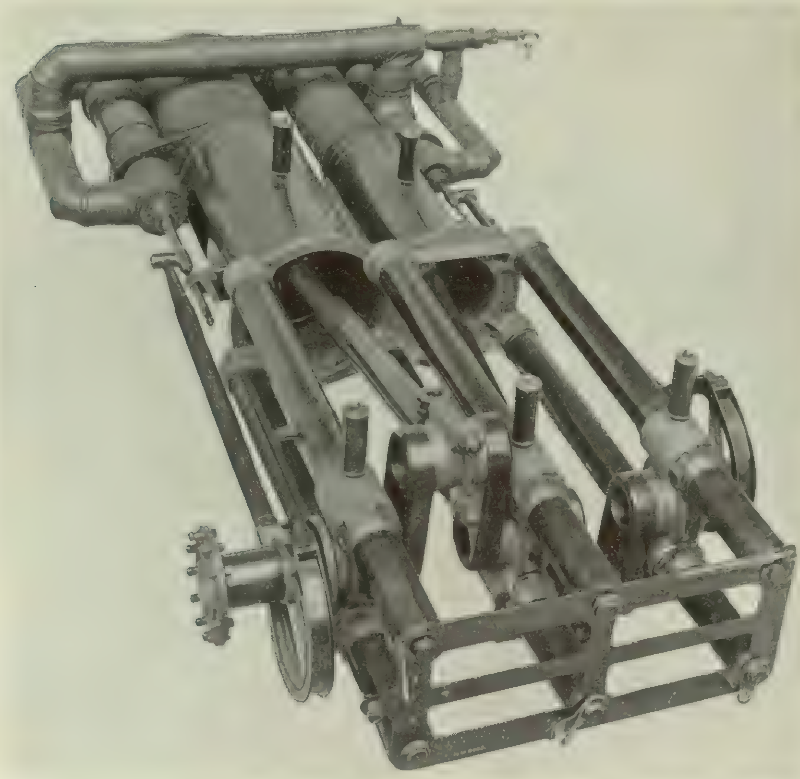
The first application for aerial propulsion of an internal combustion engine using liquid fuel was made by Baumgarten and Wolfert in 1879 at Leipzig, when they employed a Daimler engine for the propulsion of a dirigible balloon. The type of engine used was one of the earliest evolved by Daimler to consume benzine—the lighter forms of liquid fuel not being then readily available—and it was one of an experimental series from which the successful internal combustion engine for motor-car propulsion was later developed. Unfortunately the experiments



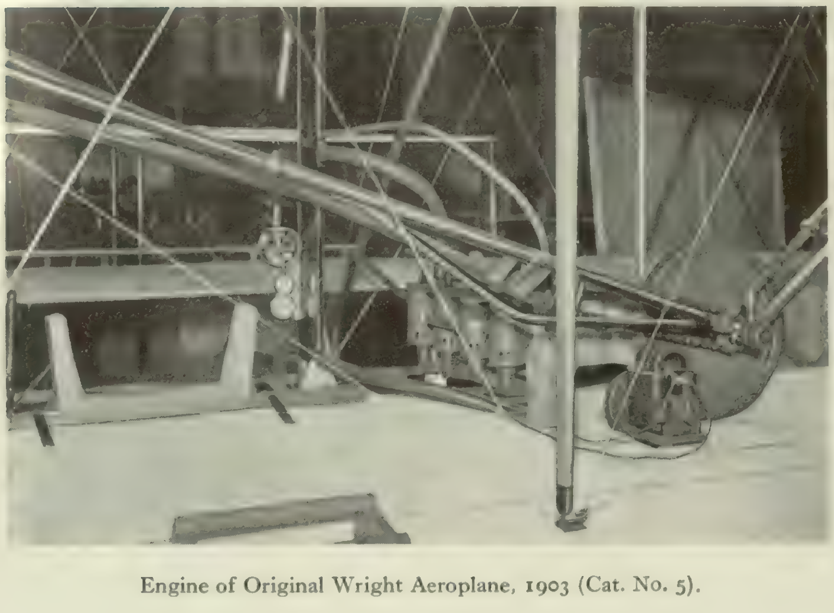
Engine of Henson's Model, 1843 (Cat. No. 1).

Stringfellow's Engine and Boiler, 1848 (Cat. No. 2).

PLATE III



Maxim's Compound Steam Engine, 1894 (Cat. No. 4).



Engine of Original Wright Aeroplane, 1903 (Cat. No. 5).

did not supply any very useful information concerning the important power installation, as the balloon, being faulty in construction, was wrecked almost immediately on launching. During a subsequent experiment in the same year the balloon was ignited by an explosion of fuel vapour and both the aeronauts were killed.

The very important development of the internal combustion engine of the four-stroke type using liquid fuel, introduced by Dr. N. A. Otto in 1876, was continued by Daimler and others with a view of evolving a satisfactory engine for motor-car propulsion, and from 1882 onwards Daimler concentrated on the perfection of a small high-speed petrol engine, which development had a momentous bearing upon the future of mechanical flight, as will be seen later. It is sufficient at the moment to note that, in a few years, the weight of this type of engine was reduced from nearly 100 lb. per horse-power to less than a tenth of that weight.

Before passing to the consideration in detail of the various attempts made to apply steam, compressed air, and electrical power for the propulsion of aircraft, mention should be made of two successful installations of electric motors with storage batteries in dirigible balloons. The first of these was the dirigible constructed by the brothers Albert and Gaston Tissandier in 1883, and fitted with a Siemens electric motor of nominally 1·5 horse-power, weighing 121 lb. The current to drive this motor was supplied by four bichromate batteries weighing approximately 500 lb., and the motor power was absorbed by a very light two-bladed airscrew 9 ft. in diameter. After preliminary tests the dirigible succeeded, in September 1884, in flying for two hours, and, though it was not able to fly directly against the wind, it was able to execute evolutions to the right and left.

Following upon the construction of this, the first dirigible to be driven by electricity, another and more successful dirigible employing electrical power was designed and constructed by Commandant Renard, director of the military establishment at Chalais-Meudon near Paris, in collaboration with other officers. This airship, named "La France," was provided with a Gramme electric motor developing 9 horse-power, the current being obtained from chromium chloride cells. The power was transmitted through a hollow shaft to an airscrew situated in front of the vessel. The first ascent was made on September 12, 1884, when the airship was manœuvred with ease under its own power and returned to the starting point.

Subsequent ascents were even more successful, and, during September 1885, a flight was made from Meudon to Paris when various evolutions were made and the airship, completing the journey, returned to her hangar under her own power. This remarkable performance was considered as an adequate demonstration of the utility of power-driven lighter-than-air craft, and the vessel may be said to represent the first man-carrying aircraft capable of steady flight under control and able to return to the starting point.

## *IV. The Use of Steam, Compressed Air, and Electrical Power*

The inherent disadvantage of the steam engine for the propulsion of aircraft—apart from its considerable weight—was the danger from fire, and this danger was greatest in the case of lighter-than-air craft when the lifting agent was a highly inflammable gas. For this reason its application to dirigible balloons, or airships, was not for long attempted. In the case of heavier-than-air craft the danger from fire was less, but the power for weight carried was of fundamental importance if flight was to be realized.

In default of any other form of engine able to give more power for a given weight being available—the internal combustion engine not having then been sufficiently developed—several of the early aspirants to flight applied light steam engines to their full-scale experimental heavier-than-air machines.

Notable among these were Horatio Phillips, Clément Ader, and Sir Hiram Maxim. None of these experimenters succeeded in achieving what was considered to be controlled and sustained flight under power, but Maxim by concentrating on the development of light compound engines evolved a remarkably efficient steam unit. The genius of Maxim manifested itself in the design of these engines no less than in his research in regard to the relative efficiency of model aerofoils and airscrews of which mention will be made later. His experimental work in connection with the propulsion of aircraft is fully described in his book " Artificial and Natural Flight, 1909." He discusses the whole question of the " navigation of the air by the use of propellers driven by a steam engine," and he explains his preference for the compound steam unit as opposed to the oil engines and electric motors of the period.

The compound steam engines—of which there were two similar—designed by Maxim for the propulsion of his large experimental aeroplane, developed about 180 horse-power each at a steam pressure of 320 lb. per sq. in. and weighed 320 lb. each (see Plate III). He says that in 1889 his attention was drawn to some very thin and strong tubes of French manufacture suitable for generating steam, and it was only after having seen these tubes that he considered seriously the making of a flying machine. Having acquired a quantity and tested them he found that they were able to sustain very high steam pressures and, after making the necessary calculations in regard to the whole problem, he found that it would be possible to construct a heavier-than-air machine capable of raising itself in the air. The two engines, which were constructed mainly of very high grade cast steel, had cylinders which were only $\frac{3}{32}$ of an inch thick and hollow crankshafts, every part being made as light as possible consistent with strength. In each engine the high-pressure cylinder had an area of 20 sq. in. and the low-pressure cylinder 50·26 sq. in. with a common stroke of one foot. The weight of the two engines when finally completed was

640 lb. and they developed 362 horse-power at a steam pressure of 320 lb. per sq. in. The final form of tubular boiler constructed by Maxim to generate steam for these engines was of the multi-tubular three-drum type, and copper tubing was employed. The water passed first through a system of small tubes $\frac{1}{4}$ in. in diameter and $\frac{1}{60}$ in. thick, placed at the top of the boiler and beneath which was the system of larger tubes. The total area of the heating surface was about 800 sq. ft. including the feed water heater, and the whole weight of the boiler with casing, dome, and smoke stack, etc., was a little less than 1,000 lb. Liquid fuel in the form of naphtha was employed, and the burner was stated to produce a dense and uniform blue purple flame 20 in. deep. The boiler was said to generate all the steam possibly required and at any pressure up to 400 lb. per sq. in. (4).

By the year 1894 Maxim had completed the construction of the power plant and the experimental aeroplane in which it was to be installed. His intention was to determine the thrust obtained from the airscrews, of which there were two, and to demonstrate that the machine was capable of raising and sustaining itself in the air. This was to be demonstrated, in the first instance, without attempting free flight, and so, under test the machine was not allowed to rise more than about 2 ft. above the level of the steel rails on which it ran, this being effected by placing a safety track of timber, on either side of the main track, under which four wheels fixed on outriggers engaged, thus restricting the rising of the machine.

The first trial was made in 1894 with steam pressure of 150 lb. per sq. in. and resulted in none of the wheels leaving the track. A second trial, made with steam at 240 lb. pressure, resulted in the machine vibrating between the upper and lower tracks, the weight on the lower steel rails being practically nothing. Preparations were made for a third trial and the machine was tied up to a dynamometer and the engines run with the steam pressure up to 310 lb. per sq. in., when a screw thrust of 2,100 lb. was indicated. On the occasion of the third and final trial steam at 320 lb. sq. in. was used and the machine was lifted clear of the lower rails, all the outrigger wheels being engaged when about 600 ft. had been covered. When 900 ft. had been traversed one of the rear axle trees collapsed, thereby setting the rear of the machine free. Shortly afterwards the left forward outrigger wheel also got clear of the upper track and the right forward wheel tore up about 100 ft. of its track. Steam was at once shut off and the machine sank abruptly and was partially wrecked, embedding the wheels in the turf without any other marks, thereby demonstrating that it had been wholly suspended in the air. In this trial two dynagraphs were used for recording the lift of the main and front axle trees and the pencils ran completely out of the scales. Maxim calculated that the total lift in the final experiment was not less than 10,000 lb., indicating that without the restriction of the overhead rails the machine would have made a free flight.

In this experimental work Maxim very thoroughly explored the

whole problem of propulsion by steam power, and it is significant that his later experiments were concerned with the internal combustion engine and its application.

As already stated, the steam plant is inherently unsuitable for the propulsion of aircraft on account of the danger from fire and the considerable weight of the boiler and its accessories. In addition, an efficient condenser of frontal area capable of inclusion in the design of an aeroplane would have to be evolved. The problem in regard to such a condenser is that if the air passages are made large enough to reduce the resistance to flow, only the outer skin of the " pencil " of air takes up any heat and this increases the frontal area to an impossible extent. On the other hand, if the passages are made small only some 40 per cent. of the air passes through them, the remainder " packing " on the face and spilling over the edges, thereby causing wasteful resistance to forward motion. The absence of a condenser would naturally involve the carrying on the aircraft of a very large quantity of water if the flight was to be of more than a few minutes' duration, and the weight of this water would be prohibitive.

Steam was used successfully for the propulsion of model aircraft notably by John Stringfellow in 1848—as already recorded—and by Professor Samuel Pierpoint Langley, who, in 1896, tested two model aeroplanes, named by him " Aerodromes," one of which flew three complete circles covering a distance of some 3000 ft.

The steam engine as a source of power was, however, abandoned in favour of the internal combustion engine immediately the latter had been developed sufficiently to render its application to aircraft feasible.

The use of compressed air as a motive power was confined mainly to experiments on model scale. Such a power unit suffered, in common with the steam engine, from the excessive weight involved—in the case of the compressed air engine from the weight of the necessary air container. In addition, the use of compressed air to any extent for practical purposes would involve the construction of plant for replenishing the containers, and the operation of aircraft would thus be considerably restricted.

Probably the earliest successful application of compressed air for the propulsion of a model aircraft was that made by the Frenchman Tatin, who in 1879 constructed a model aeroplane fitted with a small engine with an oscillating cylinder operated from a reservoir of compressed air. The reservoir was stated to be $4\frac{3}{4}$ in. in diameter and $33\frac{1}{2}$ in. long, and it was tested to a pressure of 20 atmospheres though the working pressure was about 7 atmospheres ; its weight was said to be only about $1\frac{1}{2}$ lb. The engine drove two four-bladed tractor airscrews in opposite directions by means of gearing, and when the model was tested, being attached by cords to a central stake on a track 46 ft. in diameter, it rose on attaining a speed of about 18 miles an hour and made a flight of about 50 ft. before the power was exhausted. The power developed was measured with great care and the various data

recorded led Tatin to form the conclusion that on a larger scale a higher degree of efficiency would be obtained. He estimated that 110 lb. could be sustained and propelled in the air by the exertion of 1 horse-power, and this was an interesting conclusion in regard to the power required for flight.

Experimental work with compressed air engines for the propulsion of models was also undertaken by Lawrence Hargrave (1850–1915). He also employed steam engines, clockwork, and twisted rubber bands in his experiments, but he appears to have found the compressed air unit the most convenient source of power. A number of these power units are described very fully in various papers read by Hargrave before the Royal Society of New South Wales between 1884 and 1909. Generally they consisted of a long cylindrical container from which the air was conducted to one-cylinder or three-cylinder stationary engines. The power thus obtained was used to operate both flapping wing and airscrew driven models. In the case of the former, it is recorded that a flight of 368 ft. was made in 1890, and with the latter one of 123 ft. during the following year. Hargrave early abandoned the flapping wing method of propulsion in favour of the airscrew, and in connection with this important decision he is credited with the discovery in 1889 of the principle of the rotary engine, *i.e.* that in which the cylinders rotate about a stationary crankshaft. This invention proved later to be one of considerable importance—though it has now been largely superseded—the type being particularly adapted for the propulsion of aircraft by providing a minimum weight in construction together with smoothness in running. As conceived by Hargrave the rotary engine had three equally spaced cylinders, and the power was absorbed by three blades aligned with the axes of the cylinders, thus forming a three-bladed airscrew.

The objection to the use of electrical power for the propulsion of aircraft is the weight of the storage batteries which have to be carried, and this objection is naturally greater in the case of heavier-than-air craft. The historic dirigible constructed by the brothers Tissandier in 1883—which has already been briefly described—employed an electric motor and bichromate batteries which involved a weight of something over 400 lb. per horse-power developed. Sir Hiram Maxim stated, when considering the sources of power available for flight, that he was not able to discover any practical electric motor in use which weighed less than 300 lb. per horse-power including the necessary storage batteries. He remarked also on an electric motor used for marine propulsion which was driven by a primary battery and weighed over 1,000 lb. per horse-power. In contrast, it is interesting to note that Maxim's compound steam engines complete with boiler, etc., but without water and fuel, weighed only about 8 or 9 lb. per horse-power.

Attempts to reduce the weight of storage batteries, to such an extent as would render their use in aircraft a feasible proposition, have not yet met with any degree of success, and in view of the other power now

available, it is unlikely that the electric motor with battery will again be applied for aircraft propulsion.

The proposal to retain the storage battery or generating plant on the ground and to convey the current to the aircraft by means of cables, was considered by Trouvé in 1888, and by others, as a means of raising a helicopter type of machine for observation purposes, but the idea does not seem to have been put into practice.

Research and experiment in regard to steam, compressed air, and electrical units for aircraft propulsion virtually ceased with the advent of the internal combustion engine capable of using liquid fuel. The development of the light internal combustion engine to the stage of its first successful application to heavier-than-air craft will be dealt with in the next chapter.

## *V. The Advent of the Light Internal Combustion Engine*

Passing reference has already been made to the introduction by Dr. N. A. Otto in 1876 of the high-speed internal combustion engine working on the "Otto" or four-stroke cycle and using liquid fuel. In this type of engine the explosive mixture is drawn into the cylinder by a down stroke of the piston, compressed, ignited, and finally discharged by the positive action of the fourth stroke. The system permits of a more diluted mixture being fired by reason of the compression of a large amount of air with the charge, resulting in a less violent explosion and more sustained pressure during the working stroke than that obtained in the earlier forms of internal combustion engine. The increased speed of operation and the flywheel action compensate for the loss of even torque arising from there being but one power impulse for every four strokes of the piston.

The engine working on the "Otto" cycle was at first seriously developed for use in automobiles by Daimler from about the year 1882, and by others. By 1897 he had produced a two-cylinder vertical engine which was rated as 4·5 brake horse-power. Various designs were evolved and development, after a while, proceeded on definite lines. The trend of this development, leading to the production of engines which could be adapted for the propulsion of aircraft, is described more appropriately in the technical survey (aero-engine design) which follows.

In the year 1898 the Brazilian inventor, Santos-Dumont, applied a 3 horse-power petrol engine to his first dirigible which was tested in Paris. This was followed by a series of airships which he constructed and fitted with increasingly powerful engines. His fourth airship was supplied with a Buchet petrol engine of 7 horse-power, and it was found to be capable of holding its own against a strong wind. In later airships he used an engine of 16 horse-power. Though these experimental light-than-air craft were partly successful the power was insufficient to give adequate propulsion for proper navigation and their performances were thus restricted.

In 1902 the brothers Lebaudy employed in France an adapted four-cylinder Daimler automobile engine of 40 horse-power for the propulsion of an airship. It should be noted that this engine, and those used previously for the propulsion of lighter-than-air craft, had not been substantially lightened, and the weight reduction was not such as would permit of their application to heavier-than-air craft. The fining down of detail and consequent reduction in weight—by 1901 the lowest weight for power was about 12 lb. per horse-power—which enabled the automobile type of engine to be used for the propulsion of an aeroplane, was not undertaken until the Wright brothers designed and produced such an engine in 1903—an account of which will be given later.

The first internal combustion engine to be designed specially for use in aircraft was employed by Professor Samuel Pierpoint Langley in his experiments with a man-carrying heavier-than-air machine in 1903. Langley, who had previously used steam engines to propel his model aircraft—named by him " Aerodromes "—decided, in 1899, that the internal combustion engine would provide the maximum power for a given weight compatible with a degree of safety from fire which could not be assured with a steam engine. He endeavoured to obtain a 12 horse-power engine, the weight of which would not exceed 100 lb., but, as a suitable engine was not forthcoming, he instructed his assistant, Charles M. Manly, to design a suitable engine.

Manly finally evolved a five-cylinder water-cooled radial engine which was constructed in the workshops of the Smithsonian Institution at Washington and developed over 50 horse-power for a weight of only 187·47 lb. complete with all accessories—*i.e.* radiator, tanks, ignition system, etc.—or approximately 3·6 lb. per horse-power. This was a remarkable achievement for the period and, in particular, it indicated that there were great possibilities in a design which differed from that of the then generally accepted type—the vertical type of engine.

The design and construction of this engine, completed in 1903, is described in detail in the " Langley Memoir on Mechanical Flight " issued by the Smithsonian Institution. The publication contains also a comprehensive account of the research which led to the production of the engine. The aircraft which the engine was intended to propel was based generally on the design of the previous successful model " Aerodromes," and its development was undertaken during the years 1899 to 1903.

The trials with the engine installed which were attempted over the Potomac River on October 7 and December 8, 1903, are described in the official report of Major M. M. Macomb, who represented the War Department of the United States of America, from which the following information has been extracted. The total weight of the " Aerodrome " on the occasion of the test was about 730 lb., which was to be supported by a surface of 1,040 sq. ft. and propelled by an internal combustion engine developing over 50 brake horse-power. On

October 7, when the first trial was made, the engine was observed to work well, but on attempting to launch the machine (from the top of a house-boat) the front guy-post caught, it is said, in its support on the launching car and was not released in time to permit of free flight, but caused the front of the machine to be dragged downwards, bending the guy-post and causing the machine to plunge into the water about fifty yards from the house-boat. On the occasion of the second attempt, on December 8, a hitch again occurred in the launching, the rear guy-post appearing to drag and bringing the rudder down on the launching ways, which was followed by the collapse of the rear wings, indicating, it is said, that the machine had been wrecked in the launching, just how it was impossible to say. The collapse of the rear wings and rudder, depriving the machine of its support in rear, the front portion reared up and the whole fell into the water a few feet in front of the boat.

These unfortunate accidents which, Major Macomb says, prevented any test of the apparatus in free flight, and the consequent unsatisfactory result of the trials, together with a measure of hostile criticism, caused the United States Government to decide that it was not prepared to allot further funds for a continuation of the work which it had financed.

It will be appreciated that, owing to the accidents, the performance of the engine in the air and its efficiency under those conditions was unfortunately never determined. Dynamometer tests in the workshops indicated that the power developed was, as already stated, approximately one horse-power per 3·6 pounds of weight, and the total output, if maintained, should have been ample to raise a heavier-than-air craft and sustain it in flight. The machine, including the engine, is now preserved in the National Museum at Washington.

While Langley was conducting experiments with his man-carrying heavier-than-air craft, the brothers Wilbur and Orville Wright of Dayton, Ohio, U.S.A., were completing the construction of an aeroplane to be propelled also by an internal combustion engine. This machine was the culmination of experiments made by them with various gliders during the years 1900, 1901, and 1902 (see Handbook of the Collections Illustrating Heavier-than-air Craft).

In 1903, having satisfactorily explored the possibilities of gliding and soaring flight, they turned their attention to the application of power to the machine which had previously been strictly limited in its operation by the natural forces of the air currents and the topography of the country where the experiments had been made, their object being to produce a flying machine which could be controlled and sustained at will. This necessitated an engine able to develop sufficient power, and being, at the same time, light in weight. The Wright brothers designed such an engine, adopting the internal combustion engine, using petrol as fuel, which gave the maximum power for the minimum weight (see

Plate III). The details of the engine were carefully considered and a power unit was evolved which might have developed, at a reasonable computation, some 15 horse-power—no records of brake test are available—and weighed about 240 lb. This engine, which was water cooled, consisted of four cylinders in line of approximately 4-in. bore and 4·25-in. stroke attached to an aluminium crankcase provided with four feet on one side so that, when mounted in the machine, the cylinders were in the horizontal position. Surface carburation was employed and the ignition was by means of low-tension igniters and a generator. The power was transmitted by chain drive to two propellers situated in rear of the main planes and driven in opposite directions to neutralize the effects of torque. It is stated that these propellers, which were the result of several months of research, gave a thrust efficiency of 66 per cent.

The engine was, generally speaking, a lightened and adapted form of the four-cylinder automobile engine of the period (5).

The complete power-driven aeroplane did not at first appear wholly satisfactory to the Wright brothers, but minor improvements were made, and by December 1903 it was ready for test. So confident were they of success that they sent a general invitation to people in the neighbourhood to be present when the first flights were made. The cold December wind, however, deterred all but five people from availing themselves of the invitation. On the morning of the 17th the aeroplane was brought out on to the sandy stretch of Kitty Hawk, North Carolina, where Wilbur and Orville Wright were conducting their experiments, and between the hours of 10.30 a.m. and noon four flights were made in the presence of five witnesses and the conquest of the air had been achieved. The first flight was made by Orville Wright, and it lasted but twelve seconds; the aeroplane was, however, under control, maintained its height above the sand, and landed without damage. The succeeding flights increased in length, and at the fourth trial a flight of fifty-nine seconds was made when the machine covered a distance of 852 ft. over the ground. While the aeroplane was left unattended after the last flight it was caught by a violent gust of wind, overturned, and considerably damaged before those present were able to secure it. This unfortunate mishap prevented further experiments at that time.

Improvements in the design and construction of the 1903 aeroplane occupied the brothers during 1904 and 1905. In 1904 they made flights from a field in the neighbourhood of Dayton with an aeroplane somewhat larger than the original machine. On September 20 of that year they made a complete circle in the air for the first time on a heavier-than-air craft. In 1905 they constructed an even larger and heavier machine with a total supporting area of about 600 sq. ft. and an improved engine developing greater power. With this machine they made a flight of 18 minutes 9 seconds, covering 11·12 miles, on September 26, 1905. On October 4 they flew 20·75 miles in

33 minutes 17 seconds. The speed remained as before, approximately 30 miles per hour.

The improved Wright engines were of the vertical type with the cylinders arranged upright and not horizontally as in the original engine. Descriptions of two of these early engines will be found in the catalogue portion of the book (6, 7).

In February 1928 Mr. Orville Wright generously lent the original Wright aeroplane, complete with engine, for exhibition in the Science Museum.

# TECHNICAL SURVEY

## *VI. Aero-Engine Design*

It has already been emphasized that, until a suitable source of power became available, there could be no real success in aircraft propulsion. The introduction of the four-stroke cycle internal combustion engine by Dr. Otto in 1876 gave the initial opening from which ultimate success was achieved. From 1876 to 1885 there was a period of experiment and research when the first automobiles driven by such engines appeared ; and it became evident to the discerning mind that the internal combustion engine, even as it then existed in its slow speed form, could, in all probability, be lightened and developed to a state which would provide a power plant usable in aircraft. The early development period and the production of the first relatively high speed internal combustion engines by MM. de Dion, Bouton et Cie., in 1895, leading up to the modern high speed engine of to-day, can be followed in the Land Transport Collections (mechanically propelled road vehicles) and also to some extent in the Stationary Engine Collections of the Science Museum.

In the early development of the automobile engine various designs were evolved such as horizontal single and twin cylinder engines, vertical engines, and Vee type engines of two and four cylinders, but gradually the straight line vertical engine with two, three, four, or six cylinders came to be the generally accepted type. The first successful aeroplane, that of the Wright brothers, had, as already stated, an engine which was a lightened form of this standard type of four-cylinder automobile engine, but it was mounted in a horizontal position (5). The engine of Langley's " Aerodrome " was of the radial type, which was developed later in France, where it was looked upon as one of the most successful departures from the existing practice.

The problems which confront the aircraft engine designer are of quite a different type to those which confront the automobile designer ; the conditions to be met with are not analogous. In automobile practice the flywheel plays an important part in the steady running of the engine, particularly at slow speed, whereas in the case of the aircraft engine nothing so heavy as a flywheel proper can be included in the design. The flywheel action of the airscrew, which at high speeds is a fair substitute, takes its place, but is not efficient when the engine is running light and in early aeroplanes, when the airscrew was driven by a chain, the conditions imposed on the engine were very severe. In order to obtain more even running the designer generally increased the number of cylinders for a given volume, thus increasing the number of impulses and securing a more even torque with reduced vibration.

It was early apparent that reduction of weight could be achieved

most successfully by shortening the overall length of the engine, such reduction of length operating in two ways, *i.e.* by the direct reduction of crankcase weight, and also by the diminution of crankshaft " springiness," such reduction permitting the use of a lighter as well as a shorter crankshaft and fewer crankshaft bearings, bolts, liners, etc. Another favoured method of weight reduction was by the use of a " square " engine, a term applied to engines in which the stroke approximates to the bore of the cylinders, in some cases making the stroke even shorter than the bore, thus reducing the length and weight of the crank webs and shortening the cylinder barrels, water jackets, and water content.

By these and other such obvious methods, designers had, by 1910, produced engines of considerably less weight per horse-power than those of automobiles, but, at the same time, it may be said that prior to 1912–13 engines had only been reduced in weight sufficiently to enable aircraft to fly, very little regard having been paid to the special requirements of aircraft design and the conditions to be met with and fulfilled by the engine during flight. Although the earlier designs were to a great extent influenced by previous automobile practice a wide divergence soon took place due to the entirely different conditions to be met by aircraft during the war period (1914–18). In automobile practice silence in operation and good carburation over a wide range of speeds and loads were essential features, whereas these features were of small importance in an aero-engine.

The special features of an aero-engine differ according to the type of aeroplane in which the engine is to be installed. It should be able to function properly in practically any position, and, for at least a limited period, completely inverted. This requirement led to the modification of the usual lubrication system and the obvious necessity for a " dry sump " system in which no volume of lubricant is permitted to remain in the crankcase. (This system will be described later under its appropriate heading.) The projected silhouette and shape of the engine is now determined as far as is possible by the requirements of minimum head resistance. Maximum accessibility is required both to the external fitments such as carburetters, magnetos, pipe joints, valves, and their tappets for rapid adjustment, and also to the interior of the engine for rapid inspection and easy access for the replacement of worn or damaged parts.

Another factor to be considered is the wide range of temperature and conditions of humidity of the air which have their effect on the design of the cooling system, the lubrication system, and even on the ignition system, these effects being more fully dealt with under their appropriate headings later. The aircraft may have to undergo rapid changes of as much as 42° C., with maximum change in moisture content in the air, and with water cooling it has been found expedient to add a water temperature control by thermometer, radiator shutters, or retractable radiators, etc. At the same time the loss through evaporation must be reduced to a minimum, since the loss of water during long sustained flight becomes a matter of importance.

Still another factor which has a bearing on the satisfactory functioning of aircraft engines is the high speed of the engine coupled with the lack of rigidity existing in the members of the aircraft structure which support and steady it. Such a condition imposes unforeseen and severe stresses on every portion of the design. The violent and varying slip stream from the airscrew naturally affects the air intakes and the problem of carburation, and calls for very careful design in order to prevent changes in the conditions of carburation and interference with airflow, causing back-firing and possible ignition of the fuel in the carburetter.

Probably no part of the engine has received more prolonged attention than the ignition system, resulting in the almost universal adoption to-day of dual and completely separate installations of sparking plugs, cable leads, and magnetos, while the position of the plugs in the heads of the cylinders has been found to be of the utmost importance to ensure equal speed of ignition from each side of the dual system.

The very severe centrifugal and inertia stresses set up by rapidity of manœuvre in "aerobatics" and air fighting coupled with the necessity for the immediate response of the engine to the throttle control, demand the careful designing of the fuel system. The restrictions necessarily imposed by the structure of the machine, the complexity of the fuel distribution system in large multi-engined machines, and the use of multiple tanks to ensure constancy of fuel supply to all engines from any tank in the event of extensive damage, all complicate the problem.

Reverting to the primary consideration, the arrangement of the engine as a unit, great progress has been made in the general design of the engine and its cylinders by making the most effective use of the least possible weight of material, the introduction of high tensile alloy steels, and the results of the research carried out in non-ferrous alloys having provided the designer with materials of a quality previously unknown.

In the case of the vertical type with cylinders in line the dead weight loss per horse-power rapidly decreases after the first cylinder, but after the fourth cylinder the economy gained by the addition of more cylinders practically ceases, due to the increased size of the crankshaft and the bearings required to resist torsion, etc. This limitation naturally led designers to the grouping of the cylinders in two banks forming a V, working on a common crankshaft with two connecting rods to each crankpin. Such an arrangement with banks of four or six cylinders in each, is now accepted as the best compromise for large water-cooled engines with, in a few instances, the addition of a central vertical bank of cylinders; this latter arrangement involving three connecting rods to each crankpin, and being known as the "broad arrow" type. In addition to placing the groups of cylinders in lines, designers have from the outset been attracted by the scheme of mounting all the cylinders radially round a common crank, by which arrangement the length of the crankshaft and of the crankcase is reduced to a minimum, such engines being supplied with from three to fourteen cylinders

set in one or two planes. This radial type includes those engines in which the cylinders and crankcase revolve about the stationary crankshaft, *i.e.* the so-called rotary type, which is placed in a separate group only on account of its different operation. In both arrangements the number of cylinders should be odd, so that by firing every alternate cylinder, the complete cycle of two revolutions gives an even torque and impulse distribution ; for instance, in a nine-cylinder engine the order of firing would be 1, 3, 5, 7, 9, 2, 4, 6, 8, giving an impulse every 80 degrees of crankshaft revolution.

A saving of weight and great improvement in mechanical efficiency has been achieved by eliminating the valve tappet rod system and substituting overhead camshafts operating directly on to the valves. Further economy has been made by the use of aluminium cylinders fitted with either steel or cast-iron liners, usually screwed throughout their length into the aluminium housing blocks in order to provide close contact between the two metals and to increase the area of heat transference between them. Pistons are now universally of aluminium or one of its light alloys, and the gain in mechanical efficiency has been even greater than that of the saving of weight.

Cast iron, which is an ideal material for cylinder blocks due to its excellent wearing qualities under rubbing friction, its ease in moulding, casting, and machining, is intrinsically a weak material, particularly in tension and bending, and the sections used must therefore be thick and consequently heavy. This physical fact forced the adoption of steel cylinders, first for rotary engines and later for the other types. Steel was employed by machining the cylinders from solid ingots and also by using cast steel as a halfway measure, its wearing qualities being nearly as good as cast iron. By 1919 cast iron as a material for cylinder walls and bearing surfaces was obsolete. The modern practice of using cast aluminium cylinder blocks with liners was first introduced in the Hispano-Suiza engines. In these engines the cylinder, the head, and the water jacket are aluminium castings with threaded liners of steel screwed throughout their length into the cylinder blocks. Aluminium has a very high heat conductivity coefficient, making the cylinders more easy to cool efficiently, and the use of a threaded liner ensures ample surface of the steel liner in contact with the aluminium for heat transference from the liner to the cooling water. Weight for weight it is probable that in practice aluminium is as strong as steel or semi-steel when cast in monobloc form with integral water jackets. The monobloc system is inherently stiff, the cylinder blocks having a definite stiffening effect on the crankcase, permitting the latter to be made lighter. A method of using aluminium cylinder castings was later incorporated in the Curtiss engines by making both the cylinders and the upper half of the crankcase as one casting, which practice has now been widely adopted. For rotary engines the lined aluminium cylinder was also adopted, the Bentley rotary engines employing aluminium alloy cylinders with steel liners and cylinder heads

Having considered the major problems of design and operation to be met by the designer, it is interesting to note what makes of engine

were available for installation in the earlier forms of aircraft. It will be seen that the development of several divergent types occurred simultaneously—both as automobile and as aircraft engines—which showed no consistent trend of thought, with the exception of the engine of Langley's " Aerodrome " of 1903 which was made to the designs of Charles Manly in the workshops of the Smithsonian Institution at Washington. This engine, as already stated, was a remarkable design for the period in which it was conceived—a radial engine giving about 52 horse-power for a dry weight of 187·47 lb. or approximately 1 horse-power per 3·6 lb. Otherwise the various makers approached the problem from divergent angles. The first engine successfully used, in heavier-than-air craft, that of the original Wright aeroplane of 1903, has already been described (5). The next engine of particular note after the early Wright engines was the French Antoinette eight-cylinder Vee type which employed steam cooling of the cylinders in conjunction with an air-cooled condenser, arranged along the sides of the aeroplane fuselage, and positive fuel injection over the inlet valves controlled by a variable stroke pump. This engine made its first recorded appearance in a racing launch on the Seine during April 1905, and it was used in such early aircraft as the Blériot-Voisin experimental biplane, tested in 1906, and in Santos-Dumont's first " canard " type of aeroplane in September of the same year. During 1907 the Antoinette engine was fitted to many experimental aircraft, including the British airship " Nulli Secundus," and in 1908 it was even more widely applied, and with a considerable measure of success (53, 54). At this time several types of modified automobile engines were available, but none of them quite approached the weight per horse-power figure of the Antoinette. Certain types were, however, investigated, resulting, in due course, in the development along definite lines of the straight line vertical, the Vee, the radial, the opposed, and finally the rotary types. The period 1905–6 saw the establishment in America of the Curtiss Vee-type engine developed from the motor cycle engines constructed by Glenn Curtiss. The first water-cooled example of this engine was fitted in the Curtiss biplane which won the speed contest at Rheims in 1909; previously in its earlier air-cooled form it was used in America with considerable success. Among other designs Great Britain produced the Green vertical engine (10–13), which later became one of the most reliable engines available, and the Wolseley Vee type (41).

The appearance of the first Gnome rotary engines at the Paris Salon in December 1908 established an entirely new outlook in design. It must be remembered that at this period the prime considerations were weight and reliability, and unfortunately the Antoinette engine was somewhat difficult to maintain due principally to the fuel injection system and a faulty lubrication system, resulting in oiled and sooted plugs, while its parts were generally fragile. Fuel consumption was then of little importance as machines did not make extended flights, and the modern consideration—the average weight of the complete power plant, with fuel, oil, and water over the duration of flight specified —had not yet been formulated. Under these conditions the Gnome

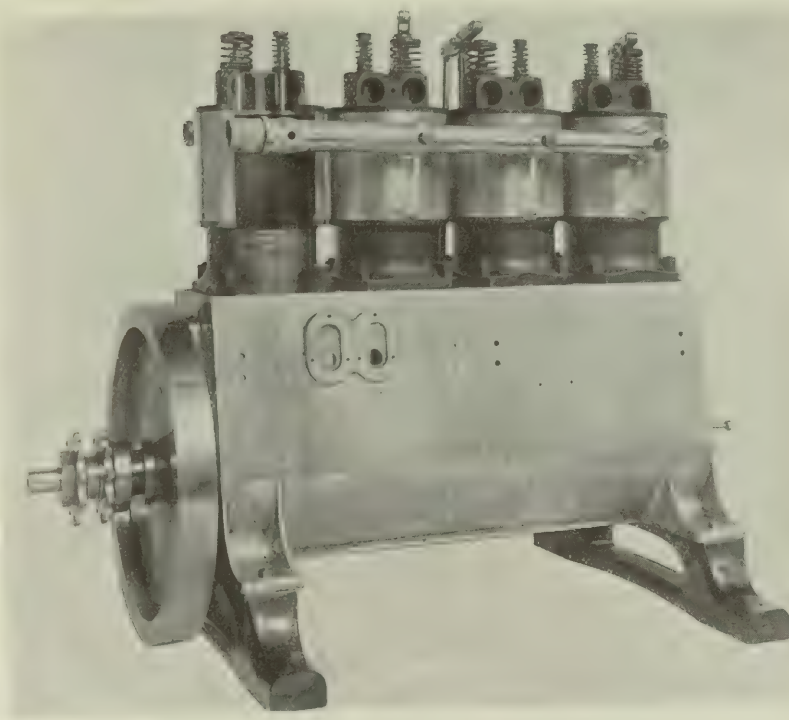
rotary engine and its later modification, the Monosoupape, established a supremacy as the lightest types per horse-power together with the absence of vibration due to all the movements being about the centre of the crankshaft or about the crank pin—pure rotation about two centres (74–78). It may be said that the Rheims Aviation Meeting in August 1909 really inaugurated European flying and gave the opportunity for the rotary engine to establish itself in popular esteem.

The period 1909 to 1914 saw the production in Europe and in America of a large number of aero-engines (too numerous to mention in detail here) of the types already briefly described. The analysis, as follows, of fifty of the principal engines produced during this period, showing the distribution of the various types, is deserving of note as indicating the trend and location of development.

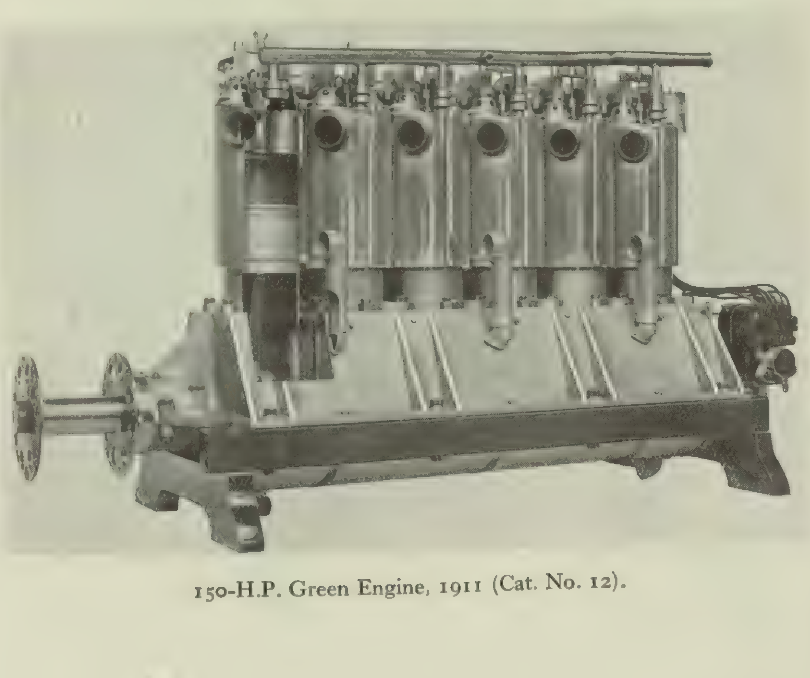
| Type. | Great Britain. | France. | U.S.A. | Germany. | Other Countries. |
|---|---|---|---|---|---|
| 4 and 6 cyl. vertical | 3 | 3 | 1 | 9 | 1 |
| 8 cyl. Vee | 5 | 6 | 2 | — | 3 |
| Radial, fan | — | 3 | — | — | — |
| Radial, complete | 1 | 3 | — | — | — |
| Rotary | — | 3 | — | — | — |
| Opposed | 1 | 3 | — | — | — |
| Unorthodox | — | 1 | — | — | 2 |

It will be seen that there was no settled conviction of the merit of any one type except in the case of Germany, which had three times the number of vertical engines compared with Great Britain or France. The French makers developed the rotary, and showed a decided preference for the fan and complete radial air-cooled types ; they were also the only nation to pay serious attention to the possibilities of the opposed type. The advent of war in 1914 at once emphasized the importance of factors other than that of simple weight reduction.

The increased range required, and the losses of aircraft through engine failure, demanded greater reliability, ease of maintenance, and accessibility, while the necessary rapidity of manœuvre called for engines of short length, concentrated mass, and rapid response to control. The demand for increased climbing power and higher " ceiling " produced decided improvement in the weight to power ratio without the sacrifice of strength and reliability, and the " ceiling " general in 1914 of some 7,000 ft. was increased to 30,000 ft. by 1919, in spite of the fact that the decreased density of the air with increase of altitude diminishes the power that the engine without supercharging can develop. Approximately the power loss at 15,000 ft. is about 45 per cent. of that given at ground level. Long range bombing and reconnaissance brought out the importance of low fuel consumption, calling for the close study of thermal efficiency in conjunction with the weight to power ratio, leading to increased engine speeds, while at the same time aerodynamic requirements called for slower airscrew speeds.

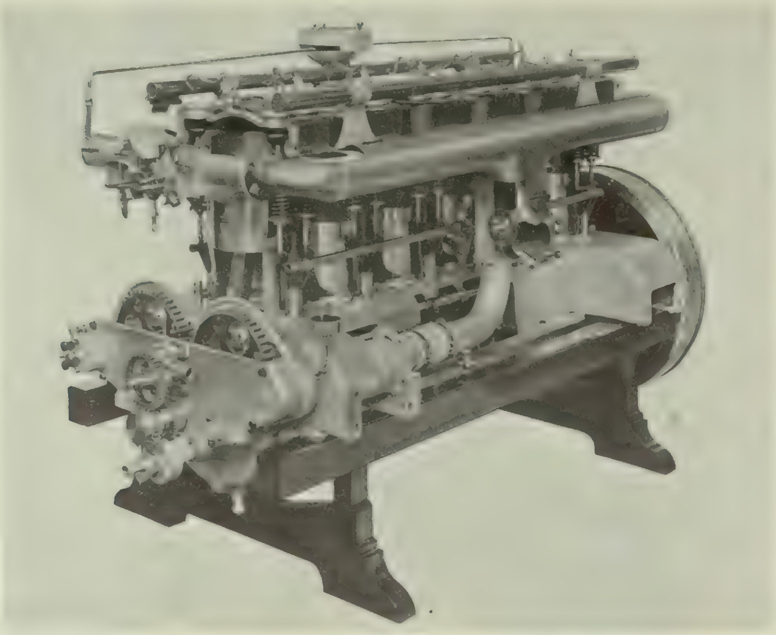


30-H.P. Wright-Bollée Engine, 1909 (Cat. No. 6).

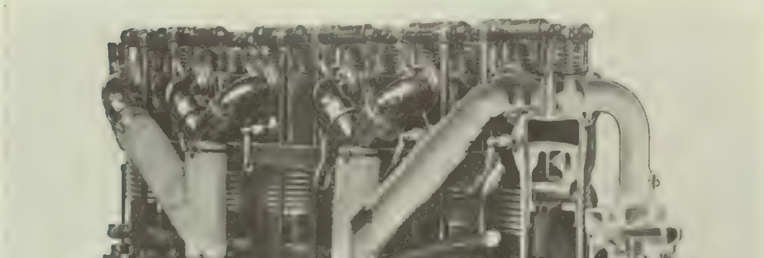


150-H.P. Green Engine, 1911 (Cat. No. 12).

PLATE V



180-H.P. Zeppelin-Maybach Engine, 1915 (Cat. No. 20).



230-H.P. Benz Engine, 1917 (Cat. No. 26).

The increased power required in later types of aircraft led to the installation of multiple engines. In 1914 this country depended for the supply of engines to a large extent on other countries, particularly France, whose Gnome and Le Rhône engines were largely in use. Great efforts were called for to extend the sources of supply, and at the close of the war period Great Britain had gained a high place in design merit and was also well equipped for the supply of all the engines required.

Generally speaking, the tendency during the war period (1914–18) was towards a heavier aeroplane, though there were two occasions when the development of light weight engines reversed this, the engines concerned being the 80 horse-power Clerget and Le Rhône and the A.B.C. "Wasp."

The reduction in weight for horse-power of war period engines in general is shown by the following table compiled from the mean of published figures :—

| | 1914. | 1915. | 1916. | 1917. | 1918. | 1919. | |
|---|---|---|---|---|---|---|---|
| Water-cooled | 4·05 | 3·75 | 3·4 | 2·8 | 2·6 | 2·2 | Approximate weight in lb. per h.p. of engine only, without accessories. |
| Air-cooled . | 4·0 | 3·0 | 2·6 | 2·1 | 2·0 | 1·9 | |

With the cessation of hostilities in 1918 there occurred a lull in the production of aircraft engines in all the leading countries, owing to there being small demand for engines for commercial use and to the enormous stocks of surplus material. It was found that the ultra-light air-cooled radial was not sufficiently robust for commercial usage, and after a period of experimental development there emerged the advanced series of the now famous Napier "Lion" engines which, with the already established Rolls-Royce "Eagle" engine, the Siddeley "Puma," and the "Liberty" engines, provided the power units for the larger aircraft (18–36–49–51–52).

By 1922 the "Jupiter" radial engine of the Bristol Aeroplane Company had been proved so efficient, light, and reliable, that its performance was strictly comparable with that of the established water-cooled type (65). In order to encourage development of the radial type the British Air Ministry had issued in 1917 what was known as an "ideal" specification for a radial air-cooled engine of large power, the results asked for being acknowledged as difficult of attainment at that time. A result was the production of the Armstrong-Siddeley "Jaguar" engine, which proved very efficient and became one of the most widely used engines of this type both for the aircraft of the Royal Air Force and for commercial machines at home and abroad (66). The Bristol "Jupiter" was likewise developed, and it is also very largely used in Great Britain and abroad, together with the Napier "Lion" series engines.

In 1923 a Light Aeroplane Competition held at Lympne in England created a demand for engines of low power, which was responded to by the manufacturers of racing motor-cycle engines. Although successful as aircraft, the ultra light aeroplane was found deficient in weather-facing power, and it lacked adequate reserve of power for climb and emergency, which led to the output of light aircraft of somewhat larger size and the evolution of somewhat more powerful engines. Of these there has been a constant development since 1923, the various manufacturers, both British and Foreign, being very numerous and almost consistently successful.

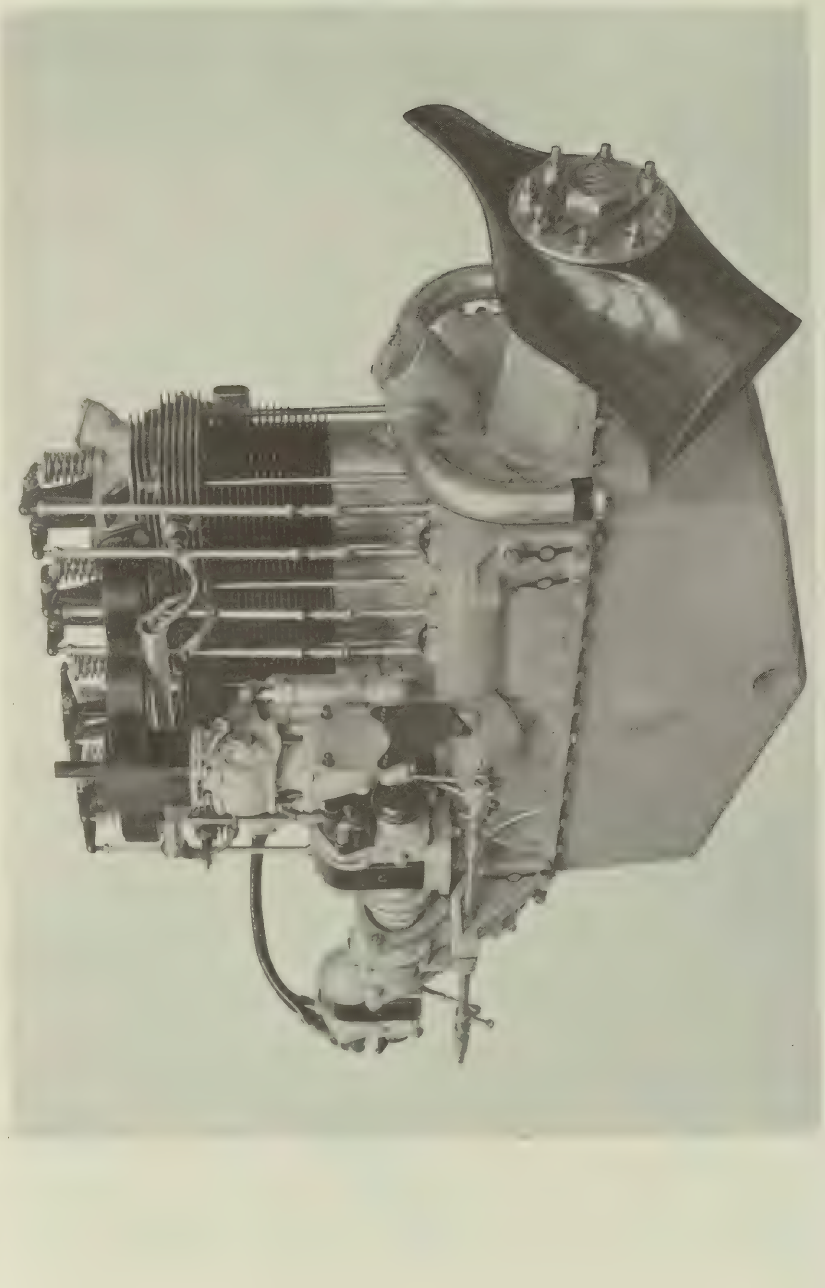
With the rise to popularity of the type of light aeroplane exemplified by the " Moth," " Avian," and " Spartan," carrying two persons and driven by an engine of some 60–80 horse-power, a semi-standardization of four-cylinder, straight line, vertical engines took place. The first of this type was the A.D.C. " Cirrus " engine (19), and to this have been added various other makes of similar design and a number of fixed radial engines of moderate power with from three to five cylinders.

The parasitic resistance of air-cooled cylinders was investigated in America and has resulted in the determination of a form of cowling which reduces this drag very considerably, thus still further helping to put the air-cooled and water-cooled types on a common basis of performance.

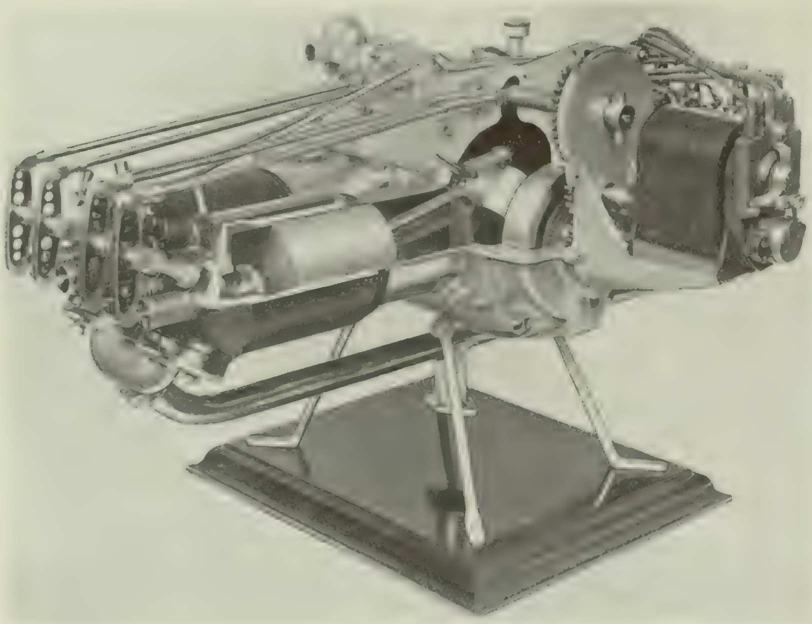
With the introduction of supercharging, which will be described later under the appropriate heading, the power output of the aero-engine was increased at altitude. Supercharging was found to lend itself particularly to the water-cooled type of engine. It will be appreciated that the two types of engines are now, to all intents and purposes, of the same general efficiency, and that the fitting of air-cooled or water-cooled engines is determined by their suitability for the particular service on which the aircraft is to be employed.

The consistent and remarkable advance made in aero-engine efficiency from the year 1914 to 1929 will be appreciated by a study of the following table compiled from data published by the leading manufacturers. By 1914 automobile designers had already reached what was rightly considered to be a high output of power per unit of cylinder volume—an approximate figure at that date being 100 cu. centimetres per horse-power or about 0·164 horse-power per cu. in. The table gives a fair indication of the advance made in power output (b.h.p.) per cu. in. in the development of aero-engines and the economy achieved at the same time in fuel consumption.

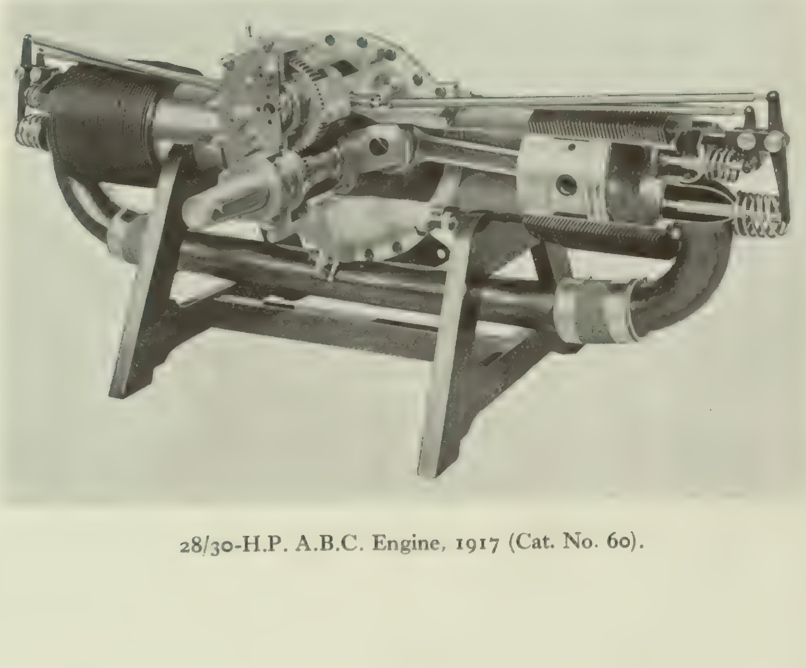
| Date. | 1914. | 1916. | 1918. | 1920. | 1922. | 1924. | 1926. | 1928. | 1929. |
|---|---|---|---|---|---|---|---|---|---|
| B.h.p. per cu. in. of cylinder volume . | 0·18 | 0·2 | 0·24 | 0·27 | 0·3 | 0·34 | 0·37 | 0·4 | 0·41 |
| Fuel consumption in pints per b.h.p. hour | 0·62 | 0·6 | 0·57 | 0·55 | 0·52 | 0·5 | 0·48 | 0·46 | 0·41 |



75 85-H.P. Cirrus Engine, Mark II, 1925 (Cat. No. 19).



50/60-H.P. Darracq Engine, 1909 (Cat. No. 62).



28/30-H.P. A.B.C. Engine, 1917 (Cat. No. 60).

It will be seen that, starting from an already advanced stage of design and efficiency, the output per cu. in. as here recorded has been increased 2·278 times, while the fuel consumption has been reduced by some 34 per cent.

### *Vertical Type Engines*

This group comprises a large number of designs developed mainly in Germany, with one outstanding British example. French manufacturers have not shown any sustained interest in the development of this type, preferring the radial, rotary, or Vee arrangement. In America a few makers have produced and developed vertical engines, but the Vee type engine is found in greater numbers. In Italy the vertical type has been developed and the engines are comparable with those produced by the German designers, who have led consistently in the production of the vertical type to the virtual exclusion of others whenever high power was required. The German " Argus " engine of 1910 was one of the first designs and was widely used on the early " Taube " type aircraft, being superseded later by the " Mercedes " engine produced by the Mercedes-Daimler Company.

The Mercedes engine was awarded the £5,000 prize of the Automobile Technical Society in 1911 ; remarkable flights were made with it during 1910–11, and by 1912 it had established itself, together with the Benz engine, as the most reliable and favoured type made in Germany. The Benz won the Kaiser Prize of £2,500, and this was followed by a flight by Hirth of three hours' duration, a very remarkable performance for the period.

Both the Benz and the Mercedes designs were thoroughly tested in automobile races such as the Prince Henry Trophy, and were brought to perfection before being used for aircraft propulsion. At the same time the " Green " engine in England won for itself a reputation for reliability, the 35 horse-power size being fitted in the first Avro biplane of 1911. The 60 horse-power four-cylinder model won the Patrick Alexander Engine Competition in 1911 and was installed in many of the best British aircraft up to 1915 (10). The preference in England for Vee type and rotary engines for military aircraft led to the Green engine being developed for airship use.

During the period of the development of the Zeppelin type of airship, Maybach, a former member of the Daimler Company and a collaborator with Daimler, produced a series of highly successful engines which, however, were used almost exclusively for rigid airship propulsion.

The National Aeronautical Collection contains a large number of examples of vertical engines representative of most of the successful

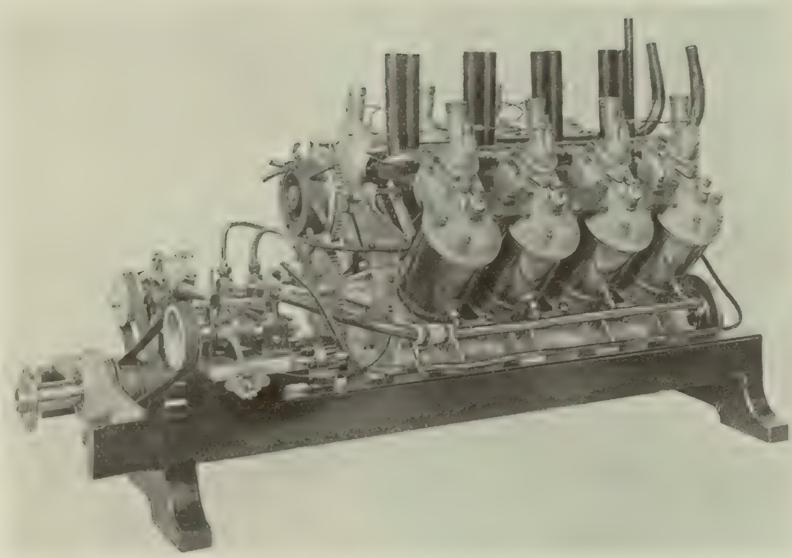
designs in various countries. The following are among those exhibited :—

| Date (approx.) | Engine. | Catalogue No. |
|---|---|---|
| 1903 | Wright, of the Original Wright Aeroplane, 4 cyl. (Plate III). | 5 |
| 1908 | Maxim's experimental, 4 cyl. | 9 |
| 1908–10 | Vivinus, 4 cyl., 70 h.p. | 8 |
| 1909 | Wright-Bollée, 4 cyl., 30 h.p. (Plate IV) | 6 |
| 1909–10 | Green, 4 cyl., 60 h.p. | 10 |
| 1911 | Green, 4 cyl., 35 h.p. | 11 |
| | Green, 6 cyl., 150 h.p. (Plate IV) | 12 |
| 1912 | Green, 6 cyl., 150 h.p. | 13 |
| | A B.C., 4 cyl., 30 h.p. | 14 |
| | Beardmore-Austro-Daimler, 6 cyl., 120 h.p. | 15 |
| 1914 | Wright, 6 cyl., 60 h.p. | 7 |
| 1915 | Beardmore, 6 cyl., 160 h.p. | 16 |
| | Rolls-Royce "Hawk," 6 cyl., 100 h.p. | 17 |
| | Zeppelin-Maybach, 6 cyl., 180 h.p. (Plate V) | 20 |
| | Isotta-Fraschini, V.4b., 6 cyl., 150–160 h.p. | 30 |
| 1915–16 | Mercedes, 6 cyl., 160 h.p. | 23 |
| 1916 | Mercedes, 6 cyl., 180 h.p. | 24 |
| 1917 | Maybach, 6 cyl., 300 h.p. | 21 |
| | Benz, 6 cyl., 230 h.p. (Plate V) | 26 |
| | Opel-Argus, 6 cyl., 180 h.p. | 27 |
| | B.H.P., 6 cyl., 200 h.p. | 18 |
| | Mercedes, 8 cyl., 240 h.p. | 25 |
| | S.P.A., 6 cyl., 200 h.p. | 32 |
| 1917–18 | Maybach M.b. IVa, 6 cyl., 260–300 h.p. | 22 |
| | Basse and Selve, 6 cyl., 270 h.p. | 28 |
| 1918 | Austro-Daimler, 6 cyl., 225 h.p. | 29 |
| 1918–19 | Isotta-Fraschini V.6, 6 cyl., 260 h.p. | 31 |
| 1919 | F.I.A.T., 6 cyl., 300 h.p. | 33 |
| 1922 | Colombo, 6 cyl., 110 h.p. | 34 |
| 1925 | Cirrus, Mark II, 4 cyl., 75–85 h.p. (Plate VI). | 19 |

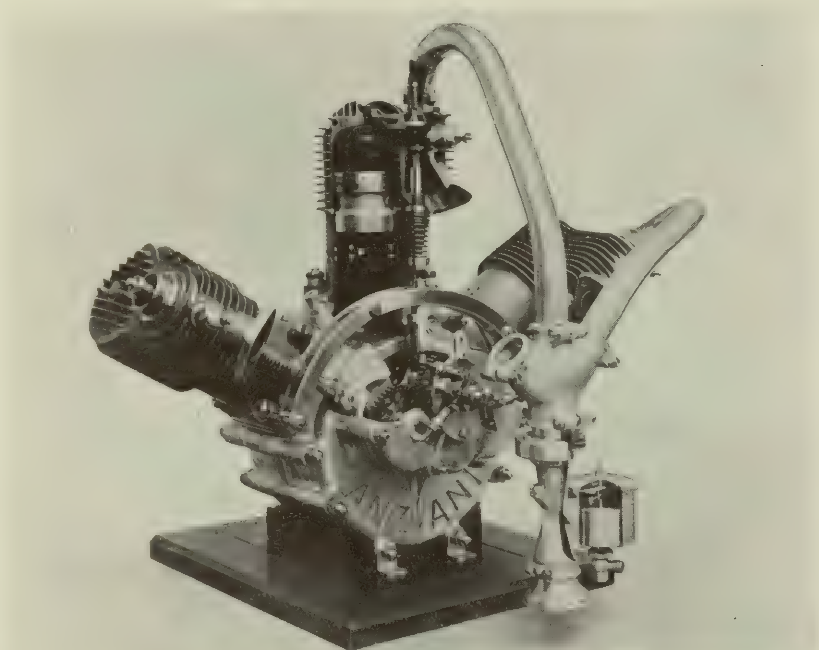
For purposes of comparison and study the purely chronological arrangement is not wholly convenient and so the descriptive matter relating to engines in the catalogue portion of this handbook has been arranged according to the countries of origin and the makers, thus better illustrating the advances made in design and power.

### *Vee Type Engines*

The Vee design was one of the earliest and has now been accepted as the best design compromise for large water-cooled aeroplane and airship engines. The first Vee engines were small two-cylinder and four-cylinder types constructed for some of the earliest automobiles, the design being later resuscitated as the obvious method of mounting two cylinders for cycle propulsion. As early as 1902 Ader, in France, produced a four-cylinder Vee type engine with the camshaft situated between the cylinders. Probably the first Vee engines with eight

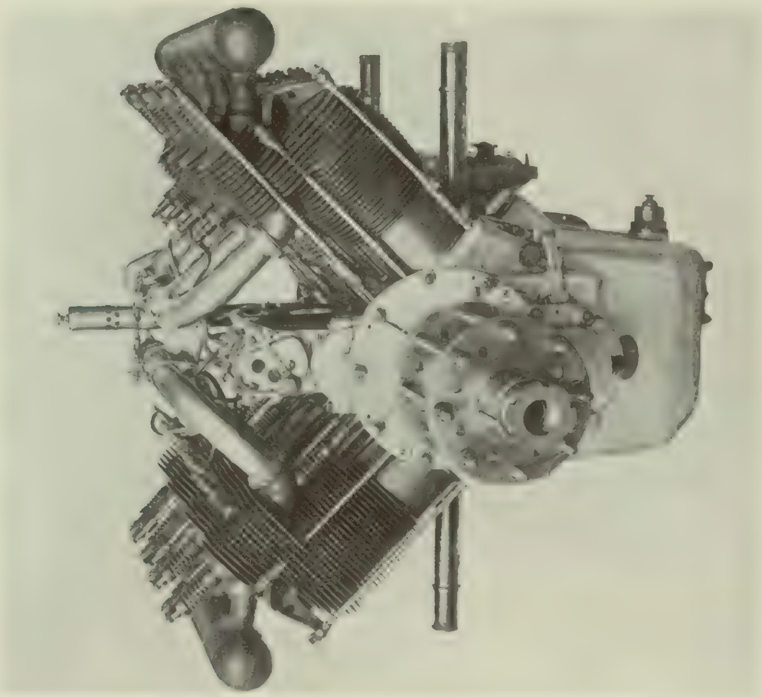


50-H.P. Antoinette Engine, 1905-7 (Cat. No. 53).

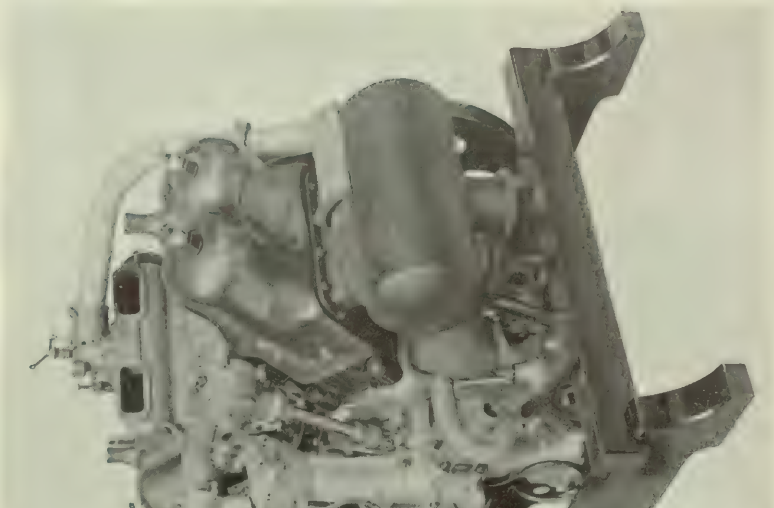



25-H.P. Anzani Engine, 1908 (Cat. No. 67).

PLATE IX



80-H.P. Renault Engine, 1913 (Cat. No. 56).



50-H.P. N.E.C. Engine, 1910 (Cat. No. 39).

cylinders in two banks of four were the 200 horse-power Darracq racing car engine of 1905 and the 20 horse-power engine designed by the firm of Rolls-Royce in the same year, but the first engine produced of a weight to power ratio suitable for aircraft installation was the French 50 horse-power eight-cylinder "Antoinette" engine of 1905, the extended adoption of which in the early days of European flying has already been alluded to.

The development of the Vee type has been world wide; it has been developed by Curtiss in America, by the firms of F.I.A.T. and Isotta-Fraschini in Italy, by Wolseley, Sunbeam, Rolls-Royce, and Napier in Great Britain, and by others, culminating to-day in the remarkable Napier "Lion" Series XI and Rolls-Royce "R" type engines of the 1929 Schneider Contest racing seaplanes—the highest development in supercharged Vee type aircraft engines (see Plate XIV).

The Collection includes a number of engines, among which are the following:—

| Date (approx.). | Engine. | Catalogue No. |
|---|---|---|
| 1905–7 | Antoinette, 8 cyl., 50 h.p. (Plate VIII) | 53 |
| 1908 | Antoinette, 8 cyl., 50 h.p. | 54 |
| 1909 | J.A.P., 8 cyl., 45 h.p. | 37 |
| | J.A.P., 2 cyl., 9 h.p. | 38 |
| 1910 | N.E.C., 4 cyl., 2-stroke, 50 h.p. (Plate IX) | 39 |
| | E.N.V., 8 cyl., 60 h.p. | 40 |
| | Wolseley, 8 cyl., 60 h.p. | 41 |
| 1911 | Clerget, 8 cyl., 200 h.p. | 55 |
| 1913 | Renault, 8 cyl., 80 h.p. (Plate IX) | 56 |
| 1915 | Rolls-Royce "Falcon," 12 cyl., 250 h.p. | 48 |
| | R.A.F., 8 cyl., 90 h.p. | 42 |
| | R.A.F., 8 cyl., 90 h.p., sectioned | 43 |
| | Curtiss, OX5, 8 cyl., 90 h.p. | 35 |
| 1916 | R.A.F. 4a, 12 cyl., 160 h.p. | 44 |
| | Sunbeam "Nubian II," 8 cyl., 164 h.p. | 45 |
| | Hispaño-Suiza, 8 cyl., 200 h.p. | 58 |
| 1917 | Hispaño-Suiza with Puteaux gun | 59 |
| | Sunbeam "Cossack," 12 cyl., 350 h.p. | 46 |
| | Rolls-Royce "Eagle VIII," 12 cyl., 360 h.p. (Plate X). | 49 |
| | Liberty, 12 cyl., 400 h.p. | 36 |
| 1918 | Napier "Lion" early type, 12 cyl., 450 h.p. | 51 |
| | Sunbeam "Manitou," 12 cyl., 300 h.p. | 47 |
| 1922 | Rolls-Royce "Condor," Series III, 12 cyl., 650 h.p. | 50 |
| 1923 | F.I.A.T., 12 cyl., 700 h.p. | 57 |
| 1924 | Napier "Lion," Series V, 12 cyl., 450 h.p. (Plate X) | 52 |

*Opposed Cylinder Engines*

This type of engine achieved some popularity during the period 1908–12, particularly for small power units. Generally such engines are designed for horizontal installation, with two or four, and rarely

six, cylinders. The design is compact and easy to install, the heads of the cylinders protruding through the sides of the nose of the fuselage do not interfere with the pilot's view in small aeroplanes, but they have the disadvantage that in order to secure symmetrical power impulses the pistons should work on to two cranks set at 180 degrees, giving theoretically perfect balance (neglecting the longitudinal component due to the cylinders being not quite in line) through the pistons approaching and receding in unison. This necessity involves a slightly longer and a heavier crankshaft than the radial form. The early Nieuport monoplane, Santos-Dumont's "Demoiselle," the German Grade monoplane, and others, employed the opposed type of engine, the makers including Dutheil-Chalmers, Darracq, and Nieuport in France, and Alvaston in England.

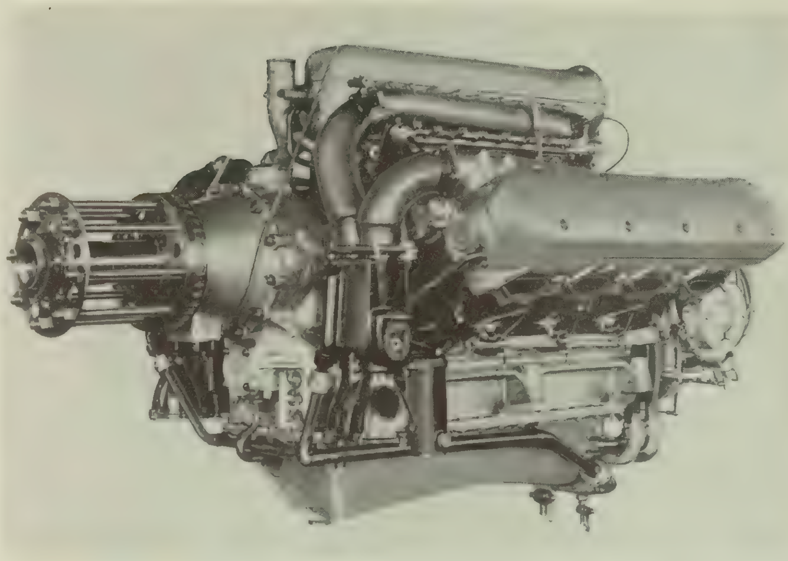
The type was not long employed for aircraft use, but it became one of the successful standard arrangements for motor cycles. With the development in this country of the ultra light aeroplane during the period 1922–3, the small opposed twin-cylinder motor-cycle engine was successfully applied, such engines as the Douglas and A.B.C. horizontal opposed types being used. These specially tuned up motor-cycle engines did not, however, prove altogether reliable under such conditions, and this led to a general re-design under the Air Ministry system of engine test, from which emerged a series of more powerful engines such as the Bristol "Cherub," the "Genet," and others. Later the 1923 Light Aeroplane Competition at Lympne in England, and the contemporary similar competitions on the continent, demonstrated that the small margin of power of such aeroplanes detracted from their utility, and a subsequent type of so-called light aeroplane became the accepted form for general and private use.

This type of light aeroplane is usually provided with an air-cooled engine of 80 horse-power and upwards, but the horizontal opposed type has at present but a very limited application.

A few of the opposed types are represented in the Collection ; they comprise :—

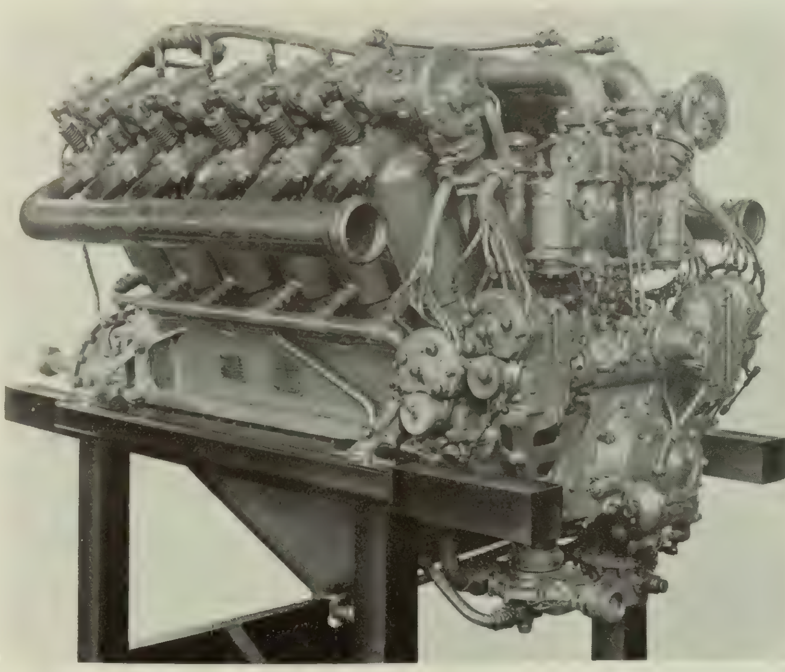
| Date (approx.). | Engine. | Catalogue No. |
|---|---|---|
| 1909 | Darracq, 4 cyl., 50–60 h.p. (Plate VII) . . . | 62 |
| 1911 | Nieuport, 2 cyl., 28 h.p. . . . . . . | 63 |
| 1917 | A.B.C., 2 cyl., 28–30 h.p. (Plate VII) . . . | 60 |
| 1923 | A.B.C., 2 cyl., 3 h.p. . . . . . . . | 61 |

Small-power engines of the last type were frequently used during the war period as subsidiary engines on large aircraft for driving accessories such as wireless generators, pumps, engine compressed air starters, etc.

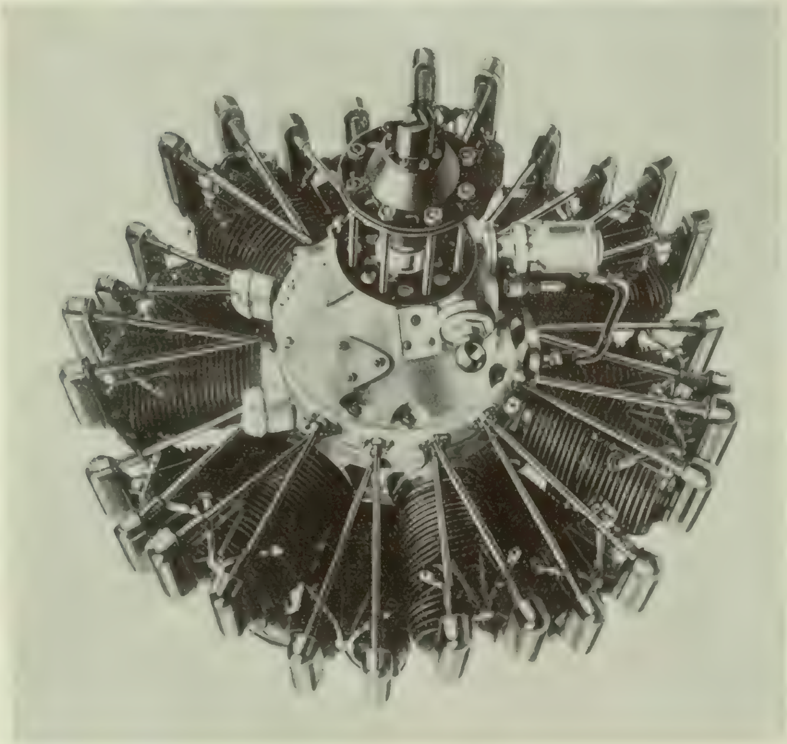


*By courtesy of Messrs. D. Napier & Son, Ltd.*

450-H.P. Napier "Lion" Engine, Series V (Cat. No. 52).

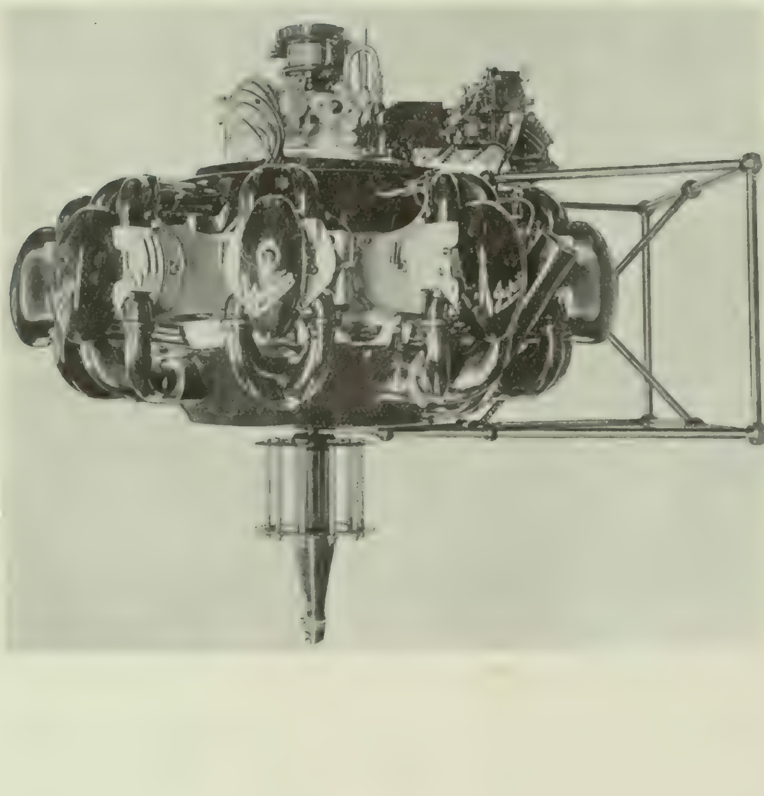


360-H.P. Rolls-Royce "Eagle VIII" Engine (Cat. No. 49).



*By courtesy of Messrs. Armstrong Siddeley Motors, Ltd.*

400/440-H.P. Armstrong Siddeley Jaguar Engine, Latest Type (1929).



*By courtesy of Messrs. the Bristol Aeroplane Co., Ltd.*

400-H.P. "Bristol" Jupiter Engine, Series VI.

### *Radial Type Engines*

This group includes those engines in which a certain number of cylinders—generally an odd number—is arranged radially about a single crankpin, forming either a complete circle or a portion thereof. The adoption of an odd number of cylinders permits a regular sequence of firing and smooth torque, whereas an even number does not do so. For example, in the case of a seven-cylinder radial engine, the order of firing would be 1, 3, 5, 7, 2, 4, 6, *i.e.* every other cylinder giving an impulse every 102·8 degrees, while a six-cylinder grouping would be fired in the order 1, 3, 5, 6, 2, 4, or 1, 3, 5, 2 4, 6, giving odd spacing between impulses ; in the latter order impulses at 0, 120, 120, 180, 120, 120, 60 degrees.

In early designs, such as the three-cylinder Anzani and the five- and seven-cylinder R.E.P. engines, a fear of trouble arising from the accumulation of lubricant in cylinders set below the horizontal (*i.e.* those with their open ends inclined upwards), restricted the placing of the cylinders to above the horizontal, resulting in the " fan " arrangement. If more cylinders were required than could be accommodated in the space above the horizontal the number was usually divided and one group was placed in a plane behind, and the cylinders spaced between those in the front row giving a " double fan " layout. With the advent of more perfect and mechanical systems of lubrication this fear was found to be groundless, and symmetrical radials became common from 1910 onwards.

As already noted, the French designers were the great protagonists of the radial engine in the early days of aviation. From about the year 1915 the radial declined, with the exception of the Anzani and the Canton-Unné types, until a fresh impetus was given by the development of the A.B.C. " Wasp " engine followed by the " Dragonfly " of 320 horse-power, both engines having the remarkably low weight to power ratio of about 1·9 lb. per horse-power. The British Air Ministry adopted the " Dragonfly " as standard for many types of service aircraft, and large numbers of these engines were in course of production towards the end of 1918, but hostilities were concluded before they had been employed to any extent in service.

Following the " Dragonfly," the Bristol " Jupiter " radial engine of 300 to 400 horse-power (as developed) established the type once more in favour as a robust and reliable design. The issue by the Air Ministry of an " ideal " specification in 1917, in order to encourage research, led also to the designing of the Armstrong-Siddeley " Jaguar," these two engines, the " Jupiter " and the " Jaguar," winning a foremost place both for use in service and commercial aircraft at home and abroad, particularly in Germany.

The Collection contains examples of the following radial engines :—

| Date (approx.). | Engine. | Catalogue No. |
|---|---|---|
| 1908 | Anzani, 3 cyl., 25 h.p. (Plate VIII) . . . | 67 |
| 1909 | Anzani, 3 cyl., 35 h.p.. . . . . . . | 68 |
| 1912 | Anzani, 10 cyl., 100 h.p. . . . . . . | 69 |
| 1913 | Canton-Unné (Salmson), 9 cyl., 130 h.p. . . | 70 |
| 1918 | A.B.C. " Dragonfly," 9 cyl., 320 h.p. . . . | 64 |
| 1921 | Bristol " Jupiter " (Series IV), 9 cyl., 400 h.p. (Plate XI). | 65 |
| 1924 | Armstrong-Siddeley " Jaguar," 14 cyl., 400 h.p. (Plate XI). | 66 |

### *Rotary engines*

The rotary type, which, before 1917 was almost exclusively developed in France, is the same in principle as the radial type, except that in the case of the rotary the cylinders and crankcase are permitted to revolve about the crankshaft, which is held stationary. Provision is, of course, made for the mounting of such fitments as the magnetos, pumps, and carburation system on stationary parts supported by the crankshaft.

The system results in marked freedom from vibration, since all the moving parts are rotating about two definite centres ; the cylinders and crankcase about the shaft centre, the connecting rods and pistons about the crankpin centre. The rotating mass also serves as an efficient flywheel, and air cooling is ensured by the passage of the cylinders through the air during revolution, but at the same time the fan action and the turbulence caused by the cylinders absorbs a considerable percentage of the power. It was generally assumed during the period 1908–15 that to ensure adequate cooling and an unobstructed exit for the exhaust gases, it was desirable to cowl in only the space adjacent to the cylinder heads, leaving all the central portion of the engine exposed, but experiments conducted with an 80 horse-power Gnome engine completely boxed in and fed with a controllable supply of air showed that quite a small amount of cold air was sufficient compared with the volume flowing past the usual cowling, and in a few cases steps were taken to arrange the cowling so that an approximation to stream-line form was secured, with corresponding increase in the performance of the machine. The " spinner " on the early Bristol monoplane scout and the stream-line fuselage of the Lee and Richards annular monoplane were designed with this end in view. Generally, the stream-line cowling was not made full use of by aircraft designers at this time, and the abnormal drag resistance of open-cowled engines, together with other important factors, led to the ultimate abandonment of the rotary

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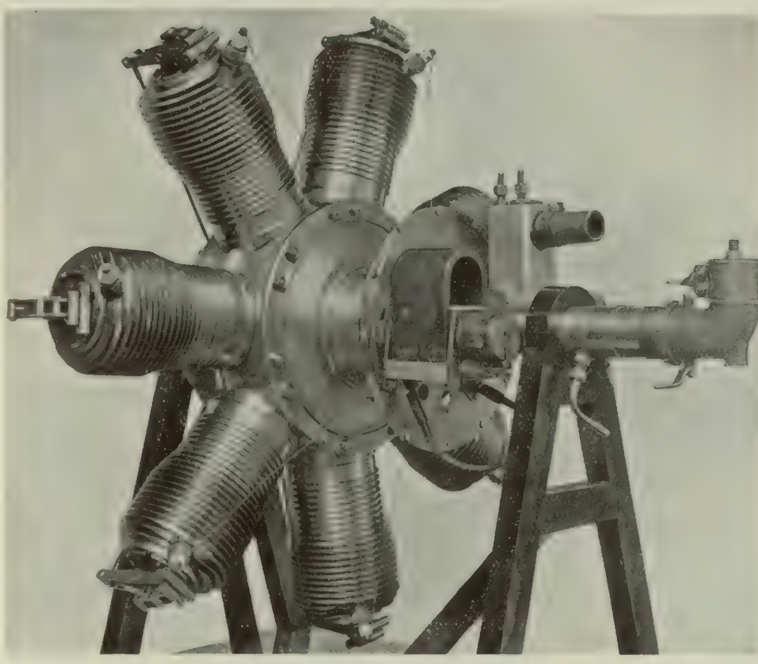
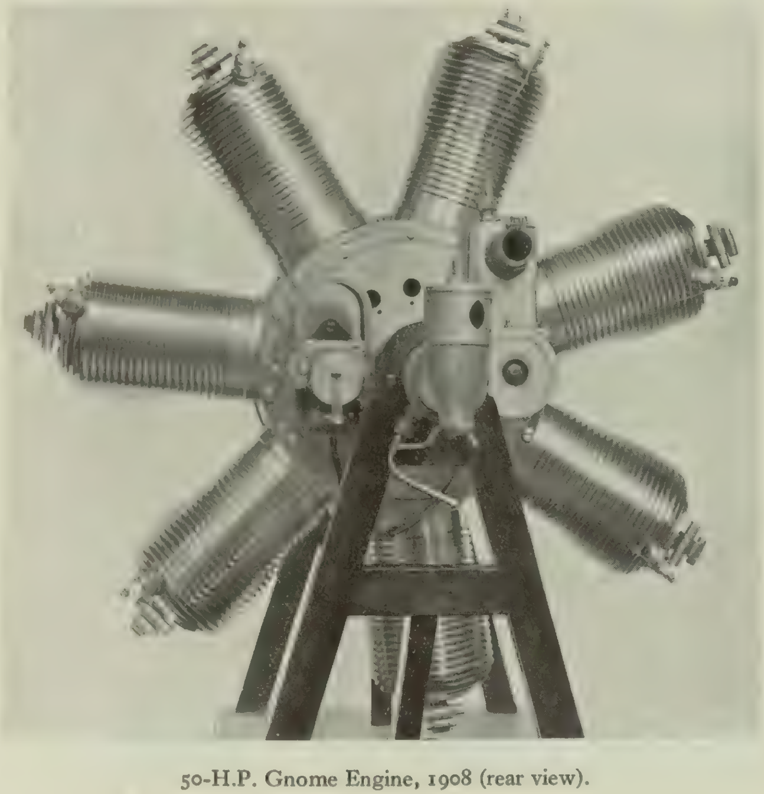
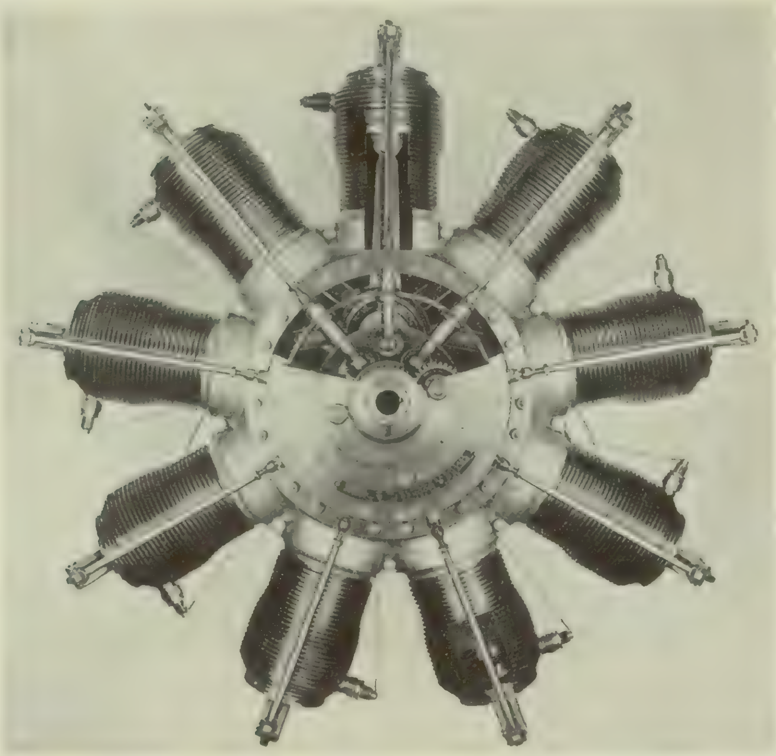


50-H.P. Gnome Engine, 1908 (Cat. No. 74).

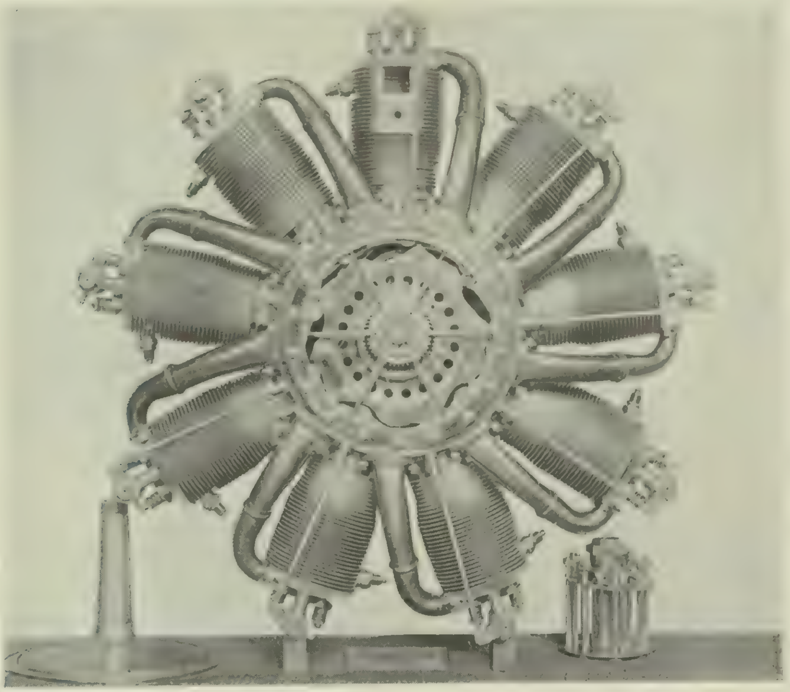


50-H.P. Gnome Engine, 1908 (rear view).

PLATE XIII



100-H.P. Monosoupape-Gnome Engine, 1914 (Cat. No. 78).



80-H.P. Le Rhône Engine, 1913 (Cat. No. 79).

type. The principal advantage of the design was the low weight for power compared with that of contemporary stationary engines of the period 1907–15.

An unsurmountable fault of the rotary type was the excessive consumption of lubricating oil owing to loss through the valves and past the pistons due to the centrifugal force of rotation. In the early days, when flights were of but short duration, this loss was not considered very serious, but with the advent of long reconnaissance flights during the war period the heavy oil consumption of the rotary engine was a great disadvantage. Another difficulty was in connection with carburation. The carburetter—which was in general simply an air-intake box with a plain jet controlled by a simple screw-down valve or a tapered jet needle—was fitted to the end of the hollow tail of the crankshaft, and when feeding the mixture into the crank-chamber the large and comparatively cold space naturally caused condensation of the atomised fuel and dilution of the lubricant unless pure castor oil was used.

But perhaps the most serious fault of the rotary is the excessive flywheel effect of the engines combined with the airscrew, resulting in the setting up of dangerous gyroscopic precessional forces militating against a rapid response to the movement of the controls, an essential for quick manœuvre in air fighting, making the machine too prone to roll and " yaw " in one direction and too sluggish in the other. In fact, when engines of large size—*i.e.* of about 200 horse-power—were fitted in fighting aircraft the pilots definitely pronounced against them on these grounds. Full credit must, however, be given to the early rotary engines for their great influence in the days when little but the lightened automobile engine was available.

A horizontal rotary engine was produced by the Adams-Farwell Company, in America, as an air-cooled automobile engine in 1905. The production of the French " Gnome " engine at the end of 1908 and its performance at the Rheims Aviation Meeting in 1909 established the value of the rotary type of 50 and 80 horse-power. These were followed by the 100 horse-power Gnome, the 80 horse-power Le Rhône and Clerget designs, and the " Monosoupape " type of Gnome. The Clerget and Le Rhône remained in wide use during the war period, and led to the design of two engines, the Bentley rotaries B.R.1 and B.R.2, which were the last designs produced before the type became obsolete due to its inherent disadvantages and the advance made in stationary engine design surpassing the weight for power figure attained by the rotary engines. The Collection contains a very comprehensive range of rotary engines of all the successful types, the following examples being on exhibition :—

| Date (approx.). | Engine. | Catalogue No. |
|---|---|---|
| 1908 | Gnome, 7 cyl., 50 h.p. (Plate XII) . . . . | 74 |
| | Gnome, 7 cyl., 50 h.p. sectioned . . . . | 75 |
| 1908–9 | Travers experimental, 3 cyl. . . . . | 71 |
| 1913 | Le Rhône, 9 cyl., 110 h.p. (Plate XIII). . . | 79 |
| | Monosoupape Gnome, 9 cyl., 80 h.p. . . . | 76 |
| | Clerget, 9 cyl., 80 h.p. . . . . . | 80 |
| 1914 | Monosoupape Gnome, 9 cyl., 100 h.p. (Plate XIII) | 77, 78 |
| 1915 | Oberursel, 9 cyl., 110 h.p. . . . . . | 83 |
| 1916 | Clerget, 9 cyl., 130 h.p. . . . . . | 81 |
| 1917 | Clerget, 9 cyl., 150 h.p. . . . . . | 82 |
| | B.R.1, 9 cyl., 150 h.p. . . . . . | 72 |
| 1918 | B.R.2, 9 cyl., 230 h.p.. . . . . . | 73 |

## *VII. Lubrication Systems*

It is essential that all the rubbing surfaces in an aero-engine should be adequately lubricated ; not only the main surfaces, but also the small bearings of the camshaft drive, the cam and lever systems, and the magneto and pump drives. The importance of adequate lubrication in regard to reliability is very great, and modern engines are much more carefully designed in this respect than those of the early period. The fact that an aero-engine may have to function in all positions renders the use of a sump containing oil into which the big ends of the connecting rods dip, or from which the oil pressure pump draws its supply, unsuitable, and this method was soon abandoned in favour of the " dry sump " system. In this system the oil base chamber is kept drained by a scavenging pump which draws away the oil as it accumulates and delivers it to an outside tank, either by way of an air-cooled oil cooler, in the case of heavy duty engines, or by utilizing the tank itself as an oil cooler. Unless the base is so formed that the oil will run to one end or the middle of the sump at maximum angle of inclination of the engine as a whole—a system which will be seen on several designs of the war period, but which makes the sump chamber very deep, and considerably increases the overall height of the engine—it is necessary to provide two scavenging pumps, one at each end of the lower crankcase, generally in conjunction with small sumps at each end.

The positive pressure system employs a pump which draws oil from the tank and delivers it under pressure to ducts, either cast in the crankcase material or made of piping, from which distributing-main small branches run to each of the main bearings. From the crankshaft bearings the oil is led into the hollow crankshaft, through holes drilled through the crank webs, to the crankpins in order to lubricate the connecting rod big end bearings. From these bearings a considerable amount of oil is thrown out by centrifugal force, and this oil is often relied on for the lubrication of the cylinder walls.

This compromise works fairly well in practice, but it is obvious that there is no positive control of the amount of oil thrown on to the walls, or of the amount which would find its way past the pistons and on to the walls of the combustion space and piston head, if the wear of the pistons became appreciable. To ensure adequate lubrication and to guard against this possibility it is common practice to provide an excess of oil thrown out and on to the walls and then to provide the pistons with scraper rings and drilled leads through the piston skirt to scrape down the excess and permit it to find its way back from the inside of the pistons to the sump. In some designs a positive feed of oil under pressure is delivered to the cylinder walls, but there is a difficulty here in the internal distribution of this oil to the surface unless an elaborate system of ducts round the piston is provided. All things considered, the splash and scraper ring method seems to give the most satisfactory service.

The gudgeon-pin in the piston is the most heavily loaded bearing in the engine, and in some cases a positive pipe lead is taken along the connecting rod to deliver oil from the crankpin bearing to the gudgeon-pin. In general, however, the splash system is relied on, and this is possible owing to the relatively small angular movement taking place in the gudgeon-pin bearing and to the usual provision of a floating bush between the connecting rod and pin which facilitates the oil distribution.

The lubrication of the camshaft, where of the overhead variety, is usually positive, the oil being led along the inside of the hollow shaft with small outlets to the camshaft bearings and in the neighbourhood of the cams, the surplus oil finding its way back to the sump by way of the timing gears and the casing of the vertical driving shaft.

In rotary engines where the fuel is admitted to the cylinders by way of the crankcase the use of a lubricant which is not soluble in petrol is imperative, and for this purpose castor oil is universally employed, but, as in the case of all vegetable oils, the action of heat sets free fatty acids which quickly " gum up " the internal portions and necessitate frequent and thorough scraping and cleaning.

Mineral oils are all miscible with the fuel, the film of oil on the cylinder walls being constantly diluted and washed away by the fuel before ignition, a certain proportion finding its way past the pistons and diluting the main body of the oil, which should in the case of aero-engines be renewed frequently. This diluted oil may also contain an accumulation of carbon in a free state from the cylinder walls, metal particles from the rubbing surfaces, and other solid impurities, but it can be reclaimed readily by simple filtering and heating processes.

The desirable features of an oil are that it should have a body sufficient to prevent metallic contact between bearing surfaces under

the maximum pressure and maximum temperature encountered, and the lowest viscosity consistent with these conditions. It should be able to resist high temperatures without undergoing decomposition and partial distillation, and have high fluidity at its minimum temperature. It should also have a high flash point, be free from oxidation, and also be free from corrosive action on metals—the worst feature of vegetable oils.

## *VIII. Cooling Systems*

Only a portion of the heat generated in an internal combustion engine is turned into useful work, the balance escaping through the exhaust valves and through the walls of the cylinders. In the latter case it has to be conducted away in order to keep the walls and cylinder head from reaching a temperature at which carbonization of the lubricant, detonation of the compressed mixture, and ultimately seizing up of the pistons and rings through heat and lack of oil would occur. This is ultimately effected by air cooling, either directly, or indirectly when the heat is first transferred to water which is in turn cooled by air by means of a radiator. Water cooling offers certain advantages ; the transmission of heat from the cylinder to water is more rapid than its transmission to air, and a much greater cooling surface in contact with air can be arranged in the radiator than is feasible on the surface of the cylinders. Air cooling by direct contact has the advantage of reducing the total weight of the power plant by the amount of the weight of the water, radiator, and piping, less the weight of metal in the necessary cooling fins. Reduced vulnerability, avoidance of loss of cooling water by leakage or evaporation and risk of damage from the effects of freezing, are other advantages. On the other hand, the drag resistance of an air-cooled engine is generally higher. Recent advances in design have put the two types approximately on the same footing in fuel economy and power developed per unit of cylinder volume. The air-cooled type always has an advantage in the weight per horse-power of the total plant over a given flight distance.

The heat which has to be dissipated is usually about 24 B.T.U. per b.h.p. per min., this figure being modified by changes in the conditions of operation.

With the usual type of engine cowling there is some removal of heat from the cylinders and jackets themselves by direct air cooling, so that the amount of heat to be dealt with by the radiator is reduced.

For air cooling the fins should be short and thin for maximum efficiency. The engine speed has a great influence on the cylinder wall temperature, the temperature rising from about 100 degrees C. at 800 r.p.m. to about 138 degrees C. at 1,800 r.p.m., but the compression ratio has a still greater bearing, and there is usually a definite ratio which will give minimum wall temperature and best mean

effective pressure. Increase of cylinder diameter slightly diminishes the heat loss to the walls. The strength of the explosive mixture has also a considerable influence on the wall temperature, the cylinder being hottest with the weakest mixture capable of giving maximum load, this being roughly an air-fuel ratio of 13·5. The maximum temperature of the head must not exceed 270 degrees C., otherwise trouble may result through pre-ignition.

With water cooling, however, it is possible to run higher engine speeds and compression ratios than with air cooling, but it is unfortunate that water has such a low boiling point; it is not an ideal cooling agent and much research has been expended to find a fluid with a higher boiling temperature which will at the same time be free from chemical action on the metal of the engine and the rubber of the piping joints, etc. Such a fluid, ethylene-glycol, which is said to fulfil the above requirements and has a boiling point of about 198 degrees C. has been experimented with in the U.S.A. This fluid is said to permit an engine to operate at 150 degrees safely, with substantial gains in several directions. The fluid has also a very low freezing temperature, *i.e.* about −17 degrees C. It is explosive and very searching.

The modern aeroplane radiator is very similar in construction to that used in automobiles, consisting generally of a block of thin brass tubes of hexagon section expanded at their ends to a larger hexagonal form so that water spaces are provided when the tubes are massed together in honeycomb form. The standard British Air Ministry tubes are of the "Anderton Brown" type, of two sizes, 7 mm. across flats and 240 to 320 mm. in length, and 10 mm. across flats by 320 to 440 mm. in length. They are of hexagonal form in the body, but the ends are expanded to a shape with one face wider, so that when assembled the vertical water spaces are greater than the horizontal spaces. This reduces the frontal area necessary.

During the war period (1914–18) the German aircraft were often fitted with horizontal radiators shaped to conform to the curvature of the centre section of the upper plane and consisting of two tanks lying fore and aft with cooling tubes of flat section arranged parallel to the plane edge and set with their major axes at an angle. Several types of British aircraft were at the same period fitted with small block radiators mounted vertically at the sides of the fuselage, and sometimes carried up to the centre section as an inverted V in front of V centre section struts. These were found to be very efficient, but, in order to reduce the types to the minimum, they were abandoned in favour of the standard section already described. Subsequent to 1918 the Lamblin "lobster pot" type of radiator was introduced but it was not very widely adopted. Many attempts to use the surface of the planes as radiating surface have been made, but although tubular wing surface radiators were introduced as early as 1907 on Santos Dumont's "Demoiselle" the only so far highly successful form has been that incorporated in the design of the Supermarine-Rolls-Royce Seaplane

S.6. In this case the water circulates between the double sheet metal wing coverings, and a very large radiating surface is obtained without any wasteful head resistance.

The amount of cooling water necessarily circulated is generally about 0·2 gallon per engine horse-power per minute, and this high rate precludes the use of thermo-syphon cooling for aero-engines. The water from the lower end of the radiator is drawn off by a pump, incorporated in the engine design, and delivered to the cylinder jackets, the ideal point of entry being in the vicinity of the exhaust valve pockets as these are the hottest points of the system. From the jackets the heated water is led to the top of the radiator and flows by gravity through the cooling passages. In order to allow for expansion and the collection and condensation of any steam formed, and to provide a reserve of water, the system generally includes a header tank forming either the top portion of the radiator or preferably a separate tank mounted in a higher position. The pump is usually of the simple centrifugal impeller type with large interior clearances to avoid breakage, or stoppage, through chance obstruction by the introduction of foreign substances. In a few cases the positive type gear pump, common in automobile practice, is used.

Due to the changed conditions of radiation in the upper atmosphere, *i.e.* the reduction of temperature and the reduced density of the air, control of radiator temperature is necessary, and the shutter type of baffle now commonly fitted to automobiles was introduced on aircraft for this purpose (85). The shutters are manually operated, in conjunction with a thermometer, by the pilot. Automatic control of the shutters is not favoured.

Another method is by the use of retractable radiators, the unit being drawn more or less completely into the body, usually on the underside, by hand control. This avoids the exposure of more than the absolutely necessary amount of radiator face to the air, reducing the drag resistance when not in full use, and it can also be arranged conveniently to supply warm air to the interior of the aircraft when desired.

Various cooling installations are shown in the full scale and model aircraft in the Collections and the different arrangements may be studied. In addition, separate exhibits are shown (84, 85).

## *IX. Ignition Systems*

Excepting in the case of the type of engine employing "compression-ignition" invented by Dr. Diesel and the modern types of "hot-point" ignition, practically all internal combustion engines, whatever their duty, are electrically ignited by the passage of an electric arc between electrodes situated in the space occupied by the compressed mixture of air and gas. The passage of this arc, commonly

referred to as the spark, is accomplished by electric current supplied from outside sources, usually incorporated in the engine design and driven from the engine itself. Aero-engines generally employ the best systems of ignition common to automobile and other practice with usually, in modern engines, the additional safeguard provided by duplication of the system, resulting in two sparks being caused simultaneously and independently in each cylinder.

There are four main systems in general use for internal combustion engines : (*a*) The high-tension rotary armature magneto ; (*b*) the high-tension stationary armature magneto with polar and sleeve inductor ; (*c*) either of the above in conjunction with a coil and accumulator system, or a coil supplied from a low-tension generator ; and (*d*) coil and accumulator, or coil with low-tension generator. In addition, many modern aero-engines are equipped with a hand-starting magneto which supplies a train of sparks through the ordinary distributing system of the magneto or high-tension distributor, which is fitted with an arm with what is known as a " trailing point " so that there shall be a path open to the hand-starting magneto current when the piston is part way down its stroke. The engine is primed with fuel and either pulled over by hand to distribute the gas in the cylinders, or it is turned over by a starting handle or mechanical means. The system (*c*) permits of easy starting by means of the trembler coil, which will produce a train of sparks when current is passed through the primary circuit although the engine is stationary.

All magnetos employ a dense field of magnetic force provided by a compound permanent magnet, its pole pieces being formed to embrace closely a circular space in which either the armature or the inductor sleeve is rotated. The current produced in the winding of the armature is dependent on the magnet design and strength.

The armature is composed of laminated soft iron plates built up on a spindle to form a suitable shape to carry the windings. These consist of a primary winding of relatively few turns of wire, in circuit with which is a contact breaker mounted on the shaft which breaks the circuit at the moment during revolution when the induced current in the primary winding is a maximum. The breakage of the circuit causes a surge of current which would cause sparking and burning of the breaker contact points, to prevent which a small fixed condenser is shunted across the contact points.

The breakage of the circuit in the primary winding induces a current of very high voltage in the secondary winding, which is composed of a large number of turns and is wound about the outside of the primary. This secondary, or high-tension current, is collected by a carbon brush from a slip ring on the shaft and led to a distributor which is rotated by the engine and leads the current to each of the sparking plugs in turn. To prevent damage to the fine windings of the secondary coil when the high-tension leads are disconnected, a safety spark gap is shunted across the winding so that the arc may be formed between the points of the gap without damage.

In the inductor type the armature is stationary and the cutting of the lines of magnetic force is made by a separate sleeve rotating between the pole faces and the armature.

A number of sparking plugs have been designed specially for use in aero-engines of different types, and some of these plugs are cut away in such a manner as to assist their cooling. The type of sparking plug which has been found to be most successful in aero-engines is generally similar to the earliest form of plug provided with mica insulation. Such a typical sparking plug consists of a central electrode surrounded by sheet mica and covered further with mica washers threaded upon it. This electrode is formed with a head at one end and a nut at the other, the mica washers being clamped firmly between. The electrode, thus insulated, is fixed into the metal body of the plug in such a manner as to provide a thoroughly gas-tight joint. The spark occurs between the central electrode and that portion of the plug which is screwed into the cylinder or an electrode attached thereto. An efficient sparking plug must be thoroughly gas-tight, and its construction will thus depend largely upon the compression of the engine in which it is to be used. In addition, it must be so designed as to avoid overheating with the attendant liability to cause pre-ignition, and this is achieved by increasing as much as possible the heat conduction through the plug. It should also be able to withstand the soot and oil present in the combustion chamber.

The Collection includes sectioned and dismounted examples of the two types of magnetos and of various forms of sparking plugs; these are described in detail in the catalogue portion (86–92).

## *X. Fuel Supply Systems*

The fuel supply and storage system of aircraft is one of the most important and least satisfactory items in the equipment. Conditions for ideal installation are not easy to arrange as the system is to a great extent determined by the space available in the body and wings of the aircraft, or in the floats of seaplanes.

A pure gravity feed would be desirable, but there is little space in aircraft where tankage could be arranged sufficient to carry all the fuel required at a height above the carburetter to give sufficient head without seriously increasing the drag resistance. It is usual, therefore, to carry the bulk of the fuel in tanks mounted inside the body, the supply to the engine being from header tanks mounted in the centre section of the upper planes in biplane construction. The fuel is pumped constantly from the main to the header tank, a margin of some 50 per cent being provided for and the surplus flowing back to the main tanks. It is also common practice to fit a reserve tank which can be brought into service in case the main supply should fail. In a few cases the

whole of the fuel is carried within the upper plane, and this is advantageous as simplifying the system and tending to reduce the risk of fire.

In the case of accident to aircraft in landing there is considerable danger of fuel from damaged tanks becoming ignited either through sparks struck by the fracturing and rubbing of metal parts, or by contact with the ignition system or hot exhaust pipes, and, although many designs of self-sealing and safety tank systems have been experimented with, none which are wholly satisfactory have so far been adopted. As long as the fuel used in aircraft is of a highly volatile nature the fire risk must necessarily remain. The introduction of engines using a relatively heavy oil of high flash point is a most valuable contribution towards safety from fire, and the development of such engines with a weight to power ratio suitable for use in aeroplanes—in addition to their present use in airships—is eagerly awaited.

The modern standard fuel piping system consists in the use of annealed copper piping used in a fully softened state, with expanded ends fitted over " olive " internal joints and gripped by metal to metal unions.

A factor to be considered in the layout of a fuel system is that centrifugal force, due to rapid manœuvre of the aircraft, shall not so influence the flow of fuel that the engine is starved, even momentarily. Another consideration in the arrangement of a system with multiple tanks and multiple engines is that any tank may be fed to any engine ; this is especially important in large multi-engine military aircraft where the danger from damage to tanks by bullets renders such a precaution necessary. A system can be easily arranged for this purpose if all sources of supply are brought to a central distributing point with leads therefrom to the various engines, but the centralized distributor is itself vulnerable and if damaged would put the whole system out of order. The system is largely used on commercial aircraft.

Fuel tanks are usually of tinned steel with turned-over seams, known as clink seams, soldered after riveting (94). For airship use, where the tankage is not liable to sudden shock, aluminium tanks are commonly used, being provided with side guides and a quick release device to facilitate jettison of the tanks in case of fire (95). The petrol joints in this case are broken by the momentum of the tank during descent in its guides.

For the raising of the fuel from the main tanks to the gravity feed header tanks some form of pump is commonly used, the glandless variety being preferred. These pumps may be driven by small airscrews working in the slipstream of the engine airscrews (96), and they are sometimes directly operated from the engine. The method of feeding from tanks lower than the carburetter by raising air pressure in such tanks was at one time common practice, but it is now discouraged due to the danger of leakage or bursting of the tanks through the failure of pressure control.

## XI. *Carburation and Supercharging*

The carburetter is the device which supplies the explosive mixture to the cylinders. An ideal mixture should have the following characteristics: it should be homogeneous throughout, and it should be of such a composition or strength to work with maximum economy under every condition of engine operation, while permitting the development of the maximum possible power. In the stationary industrial type of engine with constant speed but variable torque the above results might be approximated by using an injection valve, controlled by governor, to spray atomized fuel into the air supply. In an automobile engine, where both torque and engine speed are variable, and also in an aircraft engine, where in addition to torque and speed variation the air density constantly changes with height, the problem is much more complicated and the use of a carburetter is essential.

A carburetter is essentially a device through which a part or all the air passing to the engine enters through a restricted passage which creates a high velocity with fall of pressure. In or near the narrowest portion of the passage is placed a jet in which fuel is maintained at a determined height by a float, situated in a separate chamber, which controls a needle valve. A throttle valve which increases or decreases the velocity of the air in comparison with the atmospheric pressure acting on the surface of the fuel in the float chamber, causes a corresponding increase or decrease in the weight of fuel flowing per unit of time. The actual strength of the mixture is controlled by the size of, and the restrictions of the jet. A simple carburetter consisting of a Venturi tube, as described, and a fuel jet, will not supply a mixture of constant strength for all rates of air flow. In fact, such a mixture is not economical, since the mixture delivered should be richer at light loads and also richer to give maximum power than for maximum economy in fuel.

For maximum economy in fuel consumption the most economical air/fuel ratio is about 23 to 1, but this ratio becomes less as the density of the air decreases. On the other hand, the best ratio for maximum power requires an air/fuel ratio of about 15, this figure remaining true for all densities of the air. It is not possible for a carburetter operating at full throttle to give both maximum power and maximum economy without some form of extraneous control, since the attainment of the two conditions only concerns the actual amount of fuel supplied, but except for service requirements the condition of maximum economy is the most important. If an aircraft is to make a flight of several hours' duration it is a fact that the total weight of an engine and fuel for the duration required is less for a larger engine operating at maximum economy than for a smaller engine operating at maximum power, if both are developing the same power. Economy of operation running light, or lightly loaded, is unimportant in heavier-than-air craft, as such conditions only appertain for very short periods. In the case of lighter-than-air craft the conditions are more analagous to automobile requirements. The previously given figure of 23 for the most economical air/fuel ratio decreases to 19 at an air density of half that at

ground level, but for operating an engine at partial loads these figures are in practice reduced, since the ratios are so close to the limit of explosibility that slight changes in the conditions might easily exceed the limit. Actually the economy changes quite slowly for ratios near the optimum value, and a value of 20 at ground density is general. Constancy of mixture with variation of load is not desirable; a well-designed carburetter should give a richer mixture as the load diminishes.

In early aircraft engines the carburetters were simply readjusted automobile types, but with the introduction of rotary engines a simple type known as the " bloc-tube " was universally adopted. It consisted of a simple sliding throttle shutter with a tapered needle valve entering the fuel jet and controlling the flow in accordance with the air flow past the throttle. As engine design progressed more and more attention was given to specially designed carburetters, until to-day the practice as applied to aero-engines is quite as fully advanced as that of automobile engines.

The power given by an internal combustion engine varies approximately as the air density, diminishing with the increase in height of the aircraft and causing the horizontal speed and rate of climb to fall off constantly as the height is increased. One of the advantages of steam power, if usable, would be the avoidance of this falling off since the boiler pressure would be practically independent of atmospheric pressure, but, as already pointed out, steam power is in general unsuitable. There are several methods of increasing the power available from an internal combustion engine at altitude. One method is to install an engine of higher compression ratio than is necessary for a given power at ground level, and to operate it at full throttle while at altitude, using it with partially closed throttle at all lower altitudes than the selected operating maximum. Another method is to fit an engine of normal size for the power required at ground level but to add to it some device which supplies air at more or less constant pressure at all altitudes, so that the same amount of air and fuel enters the cylinders irrespective of the height at which the aircraft is flying. The second method is known as supercharging.

In the first method the greater power output at altitude is obtained without increase in the weight or capacity of the engine, and an increased economy in specific fuel consumption is obtained because of the higher compression ratio used. Such engines are fitted with a " gate " throttle on the carburetter control, set to the ground running power, and the engine is only opened out to full power by passing the throttle control lever through this gate at a predetermined altitude, say 5,000 ft. When running at this altitude at full throttle the pressure of the charge in the cylinder would probably not reach more than 12 lb. per sq. in. absolute, due to the reduction of the atmospheric pressure at 5,000 ft., and when running at ground level with the throttle at the " gate " position the charge pressure would probably not reach 12 lb. per sq. in. in comparison with the normal pressure of about 14 lb. in an " ungated " engine.

Another system which has been experimented with is to use an oversize engine, with a similar throttle control, and to attain high economy at low levels with such an oversize engine one method is to admit, with the explosive mixture, a proportion of inert gas from the exhaust side, the gas being first cooled, by which method the engine can be operated at full throttle with much higher compression ratios than would otherwise be possible, giving higher thermal efficiency. As the aircraft climbs to higher levels the proportion of inert gas is reduced by hand or automatic control.

In the supercharging system air is compressed by a blower, or other suitable device, and is fed to the engine at a higher pressure than the corresponding atmospheric pressure, maintaining constant density of charge and keeping the power output constant with a definite gain added by the reduced exhaust pressure. Actual tests have shown that by supercharging the increase is in the region of 5 per cent greater power output at 15,000 ft., compared with the normal loss of about 45 per cent at the same height without supercharging. Some of this increased power is, of course, used for the driving of the supercharger, and a little power is lost through the compressor heating the air slightly before entry, with consequent expansion and loss of density. Three methods of supercharging are practised. In one method the cylinder takes in a charge of air and fuel which is too rich, this charge being compressed and at the same time diluted to the proper air/fuel ratio by the admission of compressed air at the end of the intake stroke. In this method the demand for compressed air is intermittent and the compression may with convenience be made by a reciprocating type of pump which may be a portion of the engine piston skirt and its immediate surroundings, such as the Ricardo experimental system. The second method, used in U.S.A., is to compress the whole of the air before its passage through the carburetter; the third method, practised in this country and on the continent, is to insert the compressor between the carburetter and the engine.

Reciprocating pump compressors dealing with the whole charge have been tried, but their efficiency has been somewhat low, roughly about 20 per cent. The Roots type of blower gives an overall efficiency of about 80 per cent. Directly geared centrifugal compressors have given trouble through their high speed, some 20,000 revs. per min., requiring a gearing ratio which will not be suddenly accelerated without stripping the teeth due to the inertia of the impeller but are quite satisfactory if fitted with a slipping clutch system. The exhaust-driven turbine direct coupled to a centrifugal compressor can be arranged to run at 35,000 revs. per min., but there are difficulties in operation due to the very high temperature of the blading, rotor, and the casing, with liability to mechanical troubles and increased fire risk. By 1918, French engine constructors had succeeded in adding some 20 horse-power to an engine with an added weight of charger of some 18 lb. Modern results may be judged from the Rolls-Royce " F " type engine which gives 405 horse-power at 1,800 revs. per min. and 535 horse-

power at its full speed of 2,500 revs. per min. unsupercharged, these figures being increased to the equivalent of 425 and 645 horse-power respectively at the same speeds when supercharged for an altitude of 3,000 ft., and 520 and 800 horse-power respectively when supercharged for an altitude of 12,000 ft. Types of centrifugal chargers which have been developed include the Sturtevant belt-driven, the Schwade multi-stage, the Rateau exhaust turbine driven, the Moss turbine driven, the Rolls-Royce direct engine driven, and the R.A.E. type of centrifugal blower.

Examples of several different types of carburetters are shown in the Collection (99–102).

## *XII. Heavy Oil Engines*

In order to appreciate the trend of design leading to the evolution of engines of the compression-ignition, or Diesel type, for use in aircraft, it is desirable first to consider the origin of the hot-air engine, and the subsequent introduction of the practical gas engine. These types are represented in the Stationary Engine Collection and in the Road Transport Collection (Mechanically Propelled Vehicles) of the Science Museum. Considering these very briefly one may say that the hot-air engine simply utilizes the alternate expansion and contraction of air which is heated and cooled by being displaced from behind the piston to an outside heating position. Obviously the amount of heat which can be radiated through a given quantity of air in a given time is limited, and therefore the power of hot-air engines has never exceeded more than a few horse-power. On the other hand, if something is burnt in the given volume of air the heat generated can be much greater, and, prior to the evolution of the gas engine various experiments were made by utilizing quick burning chemical compounds, such as gunpowder, behind the piston. None of these led to any success before Lenoir introduced his primitive non-compression gas engine in 1860, which was quickly followed by other and more economical designs. In 1876 Dr. Otto introduced the system of compressing the charge of air and gas before ignition, and since the ratio of the explosion pressure to that of the unexploded charge is roughly 3·5 to 1 it is obvious that the higher the compression the greater the explosion pressure will be, and consequently the greater the work done by a given volume of explosive mixture. This system, both in the four-cycle form and the two-stroke form, has been the subject of constant development and is the universal system of all aero and automobile engines up to the present time.

Great as is the increase of efficiency and economy by the pre-compression system, it is limited in application due to the self-detonation of the charge if the compression used is more than about 70 to 110 lb. per sq. in., due to the heat generated during compression, and the only way to increase the compression pressure without danger of pre-ignition is by the use of fuel mixtures, commonly referred to as "doped" fuels, which, while preventing self-detonation at considerably higher compressions than normal, are of a special nature, not readily

procurable except by specially arranged supply, and therefore not suitable for ordinary private and commercially operated aircraft.

In 1900 Dr. Diesel introduced the type of engine associated with his name, which instead of compressing the explosive mixture compresses pure air only, up to pressures in the region of 500 lb. per sq. in., at which pressures the air is heated to a degree which will ignite and burn fuel introduced into it. The fuel is therefore forced into the compression space in a finely divided state by a high-pressure pump and spraying valve system, and burns in the heated air as a flame jet so long as the spray is continued, so that instead of the violent explosion and sudden pressure applied to the piston in the ordinary four-stroke system, the pressure generated in the Diesel type is maintained during a portion of the descent of the piston, and, after the fuel cut-off point, the charge continues to give pressure through expansion during the rest of the stroke. In this way the explosion pressure is increased to some 1,500 to 1,700 lb. per sq. in. with consequent gain in thermal efficiency. Also, while in the ordinary type of engine the fuel must be gasified before ignition, necessitating the use of a highly volatile fuel, in the compression-ignition system the fuel, being burnt in the compressed air, does not need to be volatile to anything like the same degree, its rapid combustion being ensured by fine division, and therefore a comparatively heavy oil can be used, with a high flash point. This fuel is relatively cheap, and removes practically all the danger from fire in case of accident to the aircraft.

It is therefore apparent that the development of the heavy oil burning engine is a matter of extreme moment to the future of aviation, not only on the score of danger from fire risks but from the standpoint of economy. The fuel consumption of the Beardmore heavy oil engines fitted in the airship H.M.A.101 is in the neighbourhood of 0·35 lb. per b.h.p. hour, and this alone should represent a saving of about 4 tons over a flight to Egypt, thus providing weight for additional passengers or cargo. In Great Britain the firm of Beardmore, and in Germany the firm of Junkers, have developed these engines with a certain measure of success. The Junkers engine is of the type in which two pistons reciprocate in one cylinder, generally referred to as the Körting system, after its originators. The Beardmore is a vertical six-cylinder engine following the recognized Diesel types in appearance (see Plate XIV), and, as developed at the present time (November 1929), is fairly heavy, the weight being in the neighbourhood of 7 lb. per h.p., but there is every likelihood of the weight being very substantially reduced as a result of the experience already gained. In considering this engine it should be borne in mind that it has been evolved to a particular specification to suit the requirements of the British Air Ministry, and it has passed a most exacting airworthiness type test. It has a cast-steel crankcase, which will probably be exchanged for an aluminium one at a later date. The specified speed is slow—950 revs. per min.—in order to drive the airscrews direct without the intervention of gearing at a speed giving good aerodynamic efficiency. It is estimated that about 25 cwt. could be saved in the engine weight in later designs.

# XIII. *Airscrews*

An airscrew is in theory a screw of constant helix considered in relation to the advance per turn made through the air, each section of the blade being given a certain angle of attack in relation to the true helix angle. In practice such a theoretical state cannot be attained, for various reasons, and the ultimately developed blade is an approximation modified by the imposed conditions under which it has to perform its functions. While it is feasible, in a wooden screw, to design the sections of the blade to theoretical requirements, in practice the sections near the root have to be considered with regard to their bending moment and resistance to torque, and so strengthened that the resulting sections are not in any sense efficient aerofoils. Each element of the blade is actually an aerofoil of infinitely small aspect ratio, the normal losses due to end slip, resulting from small aspect ratio, being avoided by the action of the adjacent sections.

The airscrew may be said to have originated with its application by Meusnier for the propulsion of an airship about the year 1784, as already stated, and it was common practice at a later date to design propelling screws as models from the tests of which the design of the full-size screw was determined. It was not until 1882 that Drzewiecki first drew attention to the benefits in design to be obtained by considering each element along the screw blade as independent and behaving in the same manner as if moving through the fluid, water, or air, in a straight line, and his method of approaching the problem is, with certain modifications found necessary for practical reasons, the basis of modern methods of calculation and design.

It will be appreciated how thorough a grasp of the essentials of design is shown by the small fabric covered airscrews of Henson's original aeroplane model of 1843 and Stringfellow's model of 1848 (see Handbook of the Collections Illustrating Heavier-than-air Craft). The method of construction there shown is theoretically sound, and consists of two tubes set a certain distance apart through a boss, and then twisted round the boss until the helix angle formed by a line joining the tube ends gives a mean tangent to the correct helix angle, from which it is obvious that all other tangents from the tips to a point near the boss will be likewise correct. This method of construction persisted for a long time, and it may be observed in the original models of Henson, and Stringfellow already mentioned, and also in Maxim's experimental machine of 1894, one of the actual propellers being shown in the Collections (109). The form may also be seen in a model of Langley's " Aerodrome " of 1903 and in an airship screw made by Santos Dumont about 1906 (107).

The first wooden screws actually used on heavier-than-air craft were those of the original Wright aeroplane of 1903 (111), but for some time afterwards a makeshift design was in common use, consisting of blades formed from sheet metal, usually aluminium, riveted or otherwise fastened to radial tubes secured to a central boss and generally

referred to as the " spoon " type. Examples of this type may be seen on the Antoinette monoplane of 1910, the Voisin biplane flown by Henri Farman in 1908, and the Roe triplane of 1909; in the last case the blades are of wood but attached in a similar manner.

The laminated wooden airscrew appeared about 1908 on the early Blériot monoplanes, the German " Taube " aircraft and others, and it remained the accepted method of construction until the successful modern development of metal airscrews. During the period 1908–14 the well-known makes of airscrews included the Lang, Integral, Chauvière, Normale, and Garuda productions, and others produced by several manufacturers of aircraft who supplied airscrews to their own design (118–122).

The laminated system consisted in the preparation of a series of laminæ cut to shape and glued together in such a way that the sections were skewed to form the approximate shape of the resulting blade form. Examples of such airscrews in the various stages of construction are shown in the Collection (114–117). The rough blade was afterwards worked up by hand to the correct sections by using templates, or by automatic forming machines, and it was then carefully balanced.

About 1916–17 attempts were made to introduce all-metal airscrews (146), the wooden airscrew being only partially satisfactory in use. The weathering qualities of wood are not sufficient to withstand the action of heavy rain when rotating, or the erosion caused by spray thrown up by the floats of seaplanes. This failure led to the reinforcement of the blade edge or to the total covering of the blade with thin sheet brass (145), but the attachment of metal to the wood in such a manner as to withstand centrifugal force and bending was difficult of attainment. When used in tropical heat warping became a serious matter, and wooden airscrews had to be kept covered when stationary, or partially protected by glueing fabric over the blades. The Leitner-Watts all-metal airscrew consisting of thin steel sheets worked to the correct blade shape and sections, being built up in a series of laminæ tapering from the boss to the tips and autogeneously welded along their edges, had a certain measure of success (147–149). The current development of the metal airscrew consists in the use of a single piece of duralumin twisted to shape, finished by grinding with special machinery, and gripped between half-bosses, the inner faces of which are formed to fit the twist of the blade. Such a method of construction was patented by Mr. S. A. Reed in the U.S.A., and it is manufactured in Great Britain as the Fairey-Reed airscrew, being used largely on modern machines (150).

It will be obvious that each section of a blade can only be designed to give maximum efficiency at one speed and angle of attack. If the top speed of the aircraft is considered, the advance made through the air per revolution will give a certain helix angle to which is added the most efficient angle of attack, but if such a screw is used at a lower speed than the top speed then the angle of attack will be greater than the most efficient angle, and if used for climbing purposes the condi-

tions will be still worse. In theory every portion of the blade should be adjustable to the most efficient angle for all forward speeds of the aircraft, but such conditions are unobtainable in practice for reasons of mechanical construction. If the blade as a whole is made capable of adjustment a considerable gain in efficiency results, though such a setting is only an approximation to that desirable—excepting for one particular portion of the blade—but it does provide a method of increasing the efficiency which can be mechanically sound and practicable. Many devices for altering the setting of the blades while the aircraft is in flight have been tried, but in most cases the high centrifugal stresses, the imperative necessity for perfect balance, the vibration stresses and the pressure on the blades of the thrust generated, have been found to militate against the wholly successful development of the designs.

In one type of airscrew—known as the Gloster-Hele-Shaw—with pitch variable during flight, the adjustment is made automatically, the variation being effected by the engine in conjunction with a governor in order to obtain the best setting for different forward speeds and air densities. In another type the pitch variation is effected by the pilot, and this is achieved in the case of the airscrew invented by Mr. W. R. Turnbull, by the introduction of a small reversible electric motor, into the airscrew boss, which operates the blade mechanism. This airscrew has, in actual test, given very promising results (151). When fixed blades are used, the greater the difference between the speed during preliminary acceleration before leaving the ground or water and the top speed of the aircraft, the greater the loss of efficiency under one or other extreme condition. An illustration of these extreme conditions is provided by the 1929 Schneider Contest seaplanes, where, due to the very high speed of the machines, the helix angle of the screw blades is very coarse, the result being that before a considerable speed, somewhere about 90 miles per hour, is reached the blades are more or less acting as flat surfaces giving great torque resistance but little thrust.

The Collection includes a comprehensive range of airscrews from the earliest to the most recent types (107–151).

## *XIV. Summary of Development*

It has been seen how the advent of the light internal combustion engine, using liquid fuel, rendered human flight—as opposed to mere ascent in the air—possible, and also how the engine was developed to meet the special requirements of aircraft. It is desirable to recapitulate very briefly here the outstanding features of this development which has made air transport an effective means of communication, in fact the most rapid and far-reaching of all methods of travel. Other methods are restricted by the configuration of the globe, and, as the medium for travel changes, so must the vehicle. The air being in regard to the earth surface all-pervading and unobstructed, it provides the best medium. In addition to this quality of continuity, it has the advantage

of presenting less of the particular resistances to motion which are present when a ship moves through the water or a vehicle moves on land, resistances which result in frictional losses. For this reason much greater speeds are possible in the air, and with safety, than are possible either on land or water.

An aeroplane demands a constant and considerable output of power in order to maintain that forward motion which renders it self-supporting, and without this power it must descend to earth ; the propulsion force is essential for this form of aircraft to remain in its element. It is obvious that the power must be adequate and sustained ; the reliability of the engine, or engines, is of supreme importance ; the power output for the weight involved a matter of general efficiency.

The earliest successful aero-engines were, as already noted, adapted automobile engines of the period, and these were applied generally without any very special efforts being made to lighten them, so that the power developed was only just sufficient for flight in the aircraft, as then designed, and provided no adequate margin. Certain types of automobile engines naturally lent themselves to adaptation for use in aircraft, and of these the vertical type with four or six cylinders was early applied. The Wright engines were of this type with four, and later, six cylinders ; a typical four cylinder water-cooled engine designed by Wilbur and Orville Wright developed 30 horse-power and weighed, without fuel, etc., about 8 lb. per horse-power. The Vee type engine was also developed from automobile practice and proved successful up to a certain point, but as the knowledge and design of heavier-than-air craft advanced there came a demand for much greater power than could be produced by the conventional types of engines within the limits of weight dictated by the design of the aircraft. This demand produced in France the Gnome air-cooled rotary engine in which the cylinders are arranged in the form of a star and rotate about a stationary crankshaft. By this arrangement it was found possible to reduce very considerably the total weight without weakening of the engine and with improved balance, the result being an engine developing 50, or in a larger size, 80 horse-power and weighing little more than 3 lb. per horse-power.

The Gnome engine was a remarkable achievement, and it had undoubtedly a considerable influence for a short period on the development of the aeroplane. At the time of its inception it was regarded as a possible permanent solution of the problem of aeroplane propulsion, but in use it was proved that the design suffered from several inherent disadvantages, chief among them being the fact that a large amount of power was wastefully absorbed in rotating the cylinders and that their cooling was not uniform. The direct result of the uneven cooling was the distortion of the cylinders at high explosive pressures and the consequent restriction in the size and power to which the engine could be developed. Another disadvantage was the gyroscopic force of rotation for which provision had to be made in the design of the aircraft. Excessive fuel and oil consumption and general

unreliability were also factors mitigating against its long-continued use.

In spite of the disadvantages of the rotary engine it was considerably developed both in France, Germany, and this country during the war period (1914–18), and it was very widely used. It was finally superseded by the development of two other types of engines ; one being the automobile type of water-cooled engine with cylinders in line—a reversion to the earliest practice—and the other the static radial air-cooled engine with cylinders arranged in the form of a star, a type originated for aircraft use.

The satisfactory power development of the automobile type of engine for use in aircraft, in the form of the vertical and Vee types, presented greater difficulties than are at first apparent ; the increased number of cylinders necessary for the higher power complicated the crankshaft and crankcase design and also involved a re-designing of the carburation system in order to obtain equal feeding for all cylinders.

The remarkable advance in the design of these engines since the latter part of the war period, resulting in increased power for weight and greater reliability, is due mainly to the supply of better materials, to a larger knowledge of the stresses to which the various parts of the engine are subjected, and to the improvement in water-cooling, lubrication, and ignition systems. The weight of a typical Vee type water-cooled aero-engine developing over 600 horse-power is now (1929) somewhat less than 2 lb. per horse-power, " dry," which indicates vividly what progress has been made during little more than a decade of development. At the same time it should be borne in mind that these engines have a high degree of reliability and are able to run for over one hundred hours continuously.

The second type of modern aero-engine, the static radial, is, as already stated, a type originated for aircraft use and it has no counterpart in automobile or other practice. It is always air-cooled and has an odd number of cylinders giving equal firing intervals. An advantage accruing from the radial engine is that it gives a compact fore and aft arrangement, in contrast to that of the vertical and Vee types, and lends itself particularly to some forms of aircraft construction. In addition it is more self-contained, and it naturally provides easier cooling and is more accessible. It is largely free from torsional vibrations owing to its having but a single crank and a very short crankshaft. As regards weight, it is lighter than the water-cooled engines and, on short journeys, it is more economical. On the other hand, for flights of considerable duration, the water-cooled engine owing to its lower fuel and oil consumption per horse-power is generally considered to provide the most power for a given weight.

It may be said that, at the present time (1929), the air-cooled radial engine provides the best unit for power up to about 300 horse-power, and that for greater power the water-cooled engine is most suitable.

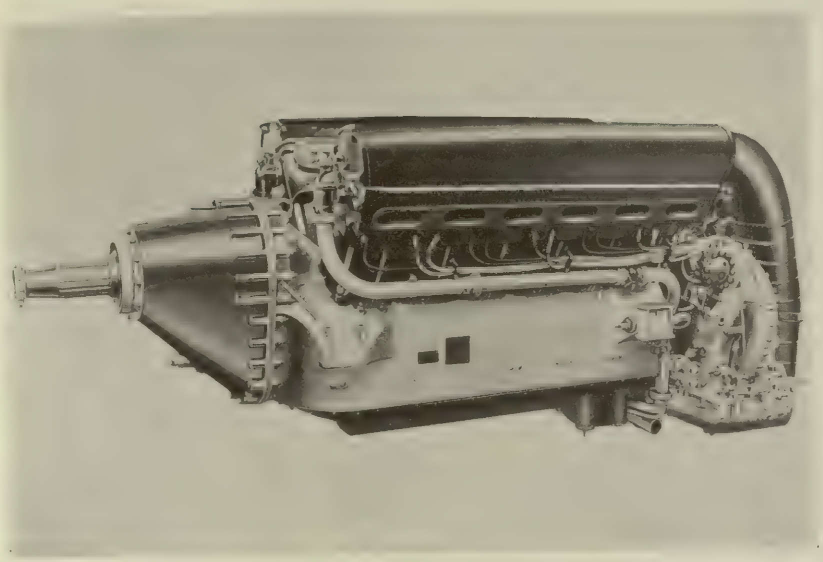
Apart from the question of cost, the latter has the advantage of a more uniform control of cylinder temperature and it provides the better shape for inclusion in the design of modern aircraft where speed is the matter of prime importance.

The tendencies now are towards the development of still larger water-cooled engines of 12, 18, and 24 cylinders, and radial engines of from 600 to 800 horse-power, such engines being geared in order to obtain the most economical airscrew speed compatible with the most efficient engine speed. The method of supercharging aero-engines to obtain the maximum output at high altitudes, and under certain conditions, is receiving constant attention.

The development of very large aeroplanes to be provided with as many as twelve engines, as in the case of the Dornier " Do. X ", has involved the introduction of a centralized control for all engines and the revision accordingly of systems of fuel supply, etc. It may be assumed that the air liners of the future will contain a large number of engines which can be regularly attended to and even partially overhauled in flight, the general responsibility for, and the immediate control of these engines, being in the hands of a chief engineer answerable to the Commander of the aircraft. Reliability in flight and consequent safety will depend largely on the multiplicity of engines furnishing an adequate margin of power under all conditions.

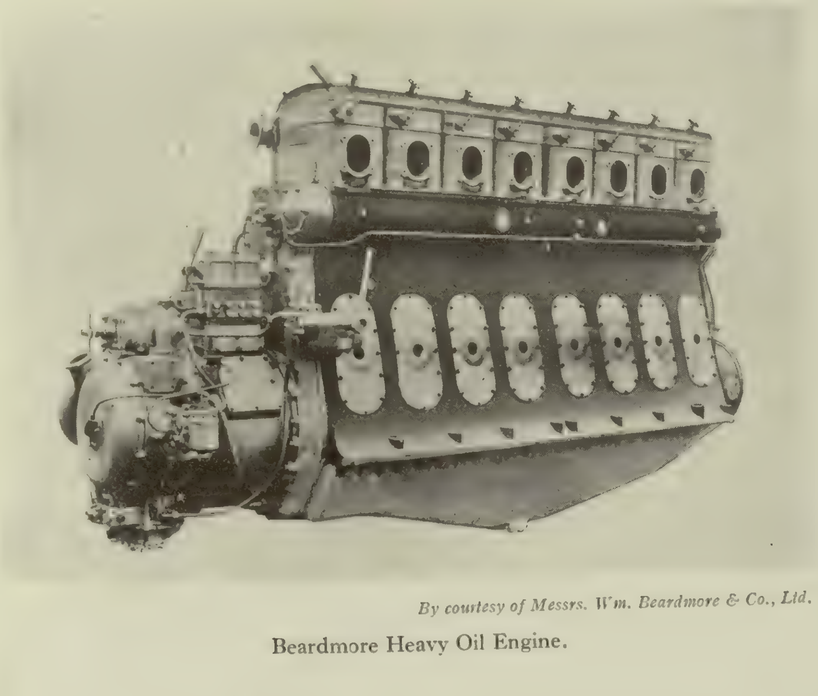
The danger from fire in an accident or forced landing when petrol is used has led to the development of compression-ignition engines of the Diesel type using heavy oil, or gas, as fuel. This type of engine is at present heavier than the conventional types of aero-engines (at the time of writing the weight is about 7 lb. per horse-power, " dry "), but it uses less fuel per horse-power hour and is more economical in use as the low-grade fuel is cheaper. The consumption has been reduced to about 0·35 lb. per h.p. hr., representing a considerable saving of weight in extended flight. The Diesel type of aero-engine as developed by the firm of Beardmore in this country has eight cylinders; the weight for power figure will, in all probability, be substantially reduced in the near future. The amount of fuel which has to be carried on a long journey has naturally an important bearing on the performance of the aircraft, and the reduction in total fuel weight for a given journey, which will be possible when a low-grade fuel is used, should materially assist in the economical operation of aircraft by enabling a larger " useful load " to be carried.

In conclusion, it may be said that future developments in regard to means for the propulsion of aircraft may be looked for in the evolution of internal combustion turbines, steam units for airship propulsion, and rocket propulsion plant; the last having already met with some measure of success.



By courtesy of Messrs. Rolls-Royce, Ltd.

Rolls-Royce, Type "R." Engine.



By courtesy of Messrs. Wm. Beardmore & Co., Ltd.

Beardmore Heavy Oil Engine.

# CATALOGUE OF THE COLLECTIONS ILLUSTRATING THE PROPULSION OF AIRCRAFT

## STEAM ENGINES

*(The exhibits are arranged in chronological order.)*

1. STEAM ENGINE FOR THE HENSON-STRINGFELLOW MODEL, 1843. **Presented by C. H. M. A. Alderson, Esq.**

This model steam engine was designed and constructed by John Stringfellow, in collaboration with William Samuel Henson, for the propulsion of a model aeroplane representing the full-sized aircraft conceived by the latter in 1842. It was placed in the car of this model at the after end, in a vertical position, and was connected with the propellers by endless cords running over the wooden pulleys shown. The engine is direct-acting and has a single cylinder 1·5 in. in diameter with a 3-in. stroke, being designed to attain a speed of approximately 300 r.p.m. The framework of the engine consists of an angle-iron structure containing the bearings for the crankshaft; it also supports the cylinder. The boiler, which is not shown, consisted of inverted truncated cones arranged round and above the furnace, and connected with a steam drum. In the projected full-sized aircraft these cones were to be fifty in number and would have presented 100 sq. ft. of heating surface. An air-cooled tubular condenser was to be provided giving a vacuum of from 5 to 8 lb., and the projected engine was estimated to develop 25–30 h.p. Inv. 1907–28.

2. STRINGFELLOW'S MODEL STEAM ENGINE AND BOILER, 1848. **Presented by Sir J. Heathcote Amory, Bart.**

The engine and boiler shown are those belonging to John Stringfellow's successful model aeroplane of 1848, the engine being mounted in position on the model, whilst the boiler and heater are shown adjacent, but without the casing which originally surrounded them.

Stringfellow was chiefly responsible for the steam-power plant of the Henson and Stringfellow model (shown adjacent) and, after the retirement of Henson, he constructed the model steam engine here shown. Later, in 1868, he exhibited a plant of one-third horse-power in a triplane shown at the Crystal Palace and also an engine of slightly over one horse-power, which was awarded the Royal Aeronautical Society's prize of £100 for the lightest steam engine in proportion to its power.

The engine shown is horizontal and double acting, the piston being 0·75 in. in diameter with a 2-in. stroke. The drive is taken by bevel gear from the crankshaft to a longitudinal shaft carrying a six-grooved pulley from which triple open and crossed driving cords passed to the propeller pulleys.

The boiler is made of thin copper, with silver-soldered joints and consists of inverted truncated cones arranged round and above the furnace. The cones are connected with a central steam drum above them and with water chambers below. The engine was subsequently used to drive a small lace machine, but has now been replaced in its original position on the model. Inv. 1908–44.

3. MODEL STEAM ENGINE AND BOILER. **Lent by the Royal Aeronautical Society.**

This model engine is said to have been used in experiments conducted between 1886 and 1892 by F. J. Stringfellow, the son of John Stringfellow, by whom it was, in all probability, constructed. It bears a close resemblance to the model steam units already described. F. J. Stringfellow attempted to continue his father's work, and in 1886 he began the construction of a biplane model, but he does not appear to have met with any success, owing possibly to lack of facilities for testing, and he was unable apparently to repeat the achievement of John Stringfellow.

References to his work are extremely meagre and do not extend beyond quotations

from his pamphlet "A Few Remarks on what has been done with Screw-propelled Aeroplane Machines from 1809 to 1892," published by him in 1892. Inv. 1919–549.

4. 180 H.P. COMPOUND STEAM ENGINE OF SIR HIRAM MAXIM'S EXPERIMENTAL AEROPLANE, 1894. Presented by Sir Hiram Maxim.

This is one of the two steam engines installed in Maxim's experimental aeroplane of 1894 which is of great interest as representing the first full-scale experiment in which a lift greater than the weight of the aircraft and crew was actually produced.

The engine is of very light construction and is made largely of high-grade cast steel, the cylinder walls being 0·0937 in. (2·38 mm.) thick. The steel crankshaft is hollow and is carried in bearings mounted on tubular members taking the thrusts from the cylinders and piston rods. The valves are of the piston type with a travel of 3 in. From the steam delivery side a lead enters the steam pipe between the high-pressure and low-pressure cylinders, and it is fitted with a spring loaded valve and nozzle which permits the steam to pass direct to the low-pressure cylinder when a certain boiler pressure is exceeded. The injector action of the nozzle prevents a corresponding rise of pressure on the exhaust side of the high-pressure valve.

Steam was provided by a multi-tubular boiler of the three-drum type, consisting of a steam drum above and two water drums below connected with a large number of small copper tubes, a feed-water heater of 0·25-in. tubing being mounted over the boiler proper. The total heating surface, including the feed heater, was about 800 sq. ft., and it was heated by 7,650 jets of vaporized naphtha delivered at a pressure of 50 lb. per sq. in. spread over a grate area of 30 sq. ft. and stated to produce a dense and uniform blue-purple flame 20 in. deep. The boiler with casing, dome, and smoke stack, etc., weighed a little less than 1,000 lb., which, with the 640 lb. weight of the two engines, gives a dry weight of under 5 lb. per h.p.

The two-bladed airscrew used, one to each engine, is 17·83 ft. diam., and of 16 ft. pitch (see No. 109).

The principal data of the engine are :—H.P. cylinder, 5·05 in. diam., 20 sq. in. area; l.p. cylinder, 8 in. diam., 50·26 sq. in. area; common stroke, 12 in.; steam cutoff, h.p., at 0·75 stroke, l.p. at 0·625 stroke; actual power developed, 181 h.p. with steam at 320 lb. per sq. in.; weight as finally completed, 320 lb.; weight of engine alone, per h.p., approx. 1·8 lb.; speed, 375 r.p.m.

See Maxim, "Natural and Artificial Flight," 1909. Inv. 1896–98 (*b*).

## VERTICAL ENGINES

(*The exhibits are arranged according to type and nationality.*)

### *AMERICAN*

5. THE ORIGINAL WRIGHT AERO-ENGINE, 1903. Lent by Mr. Orville Wright.

This engine is fitted in the original Wright aeroplane of 1903 (see Handbook of the Collections Illustrating Heavier-than-air Craft, 1929).

It was the first internal combustion engine to sustain an aeroplane in flight, and was made by the Wright brothers in their workshops specially for installation in their first power-driven aeroplane, where it drove two airscrews by means of chain drive; it is therefore provided with a light flywheel.

It is a slow speed, horizontal four-cylinder engine, water cooled by pump circulation, a small gear type pump being incorporated in the design. The explosive mixture is supplied from a wick type carburetter to spring loaded automatic inlet valves placed vertically over the exhaust valves. The latter are operated by levers from a camshaft which is chain driven from the crankshaft. Parallel to the camshaft and driven from it at the same speed is a second shaft carrying cams which operate the low-tension make and break mechanisms mounted inside the cylinder heads. The low-tension current for the igniters is supplied from a simple generator running at 2,500 r.p.m. which is friction driven from the rim of the flywheel. Contact between the points inside the cylinders is first made by the cams pressing spring levers against a spring loaded stop, the quick break which causes a spark to occur between the points being caused by the spring levers slipping off the end of the cams; the levers are returned against the spring stops by small hairpin springs.

The principal data, which are only approximate, are :—Bore, 4 in.; stroke, 4·25 in.; speed, 850 r.p.m.; volume swept out per cycle, 213·6 cu. in.; weight, 240 lb.; horse-power, as computed from contemporary automobile engines, approx. 15; nominal rating, 8 to 12 h.p. Inv. 1928–186.

6. 30 H.P. WRIGHT-BOLLÉE ENGINE, 1909. Presented by Col. Alec Ogilvie, C.B.E.

This engine was designed by the Wright brothers and made under arrangement by Mr. Leon Bollée in 1909. It was fitted in the 1908 type of Wright biplane. The engine showed a departure from standard practice in that no carburetter was fitted, the petrol being fed into the induction manifold by means of a small gear pump (not shown). The control of the engine was effected by switching off the current or by lifting the exhaust valves.

Four separate cast-iron cylinders, fitted with detachable water jackets, are mounted on an aluminium crankcase. Automatic inlet valves are employed. The exhaust valves are operated by push rods and rocker arms. The pump supplying petrol to the induction manifold was placed on the right-hand side of the engine, being driven by worm gear from the camshaft.

The lubricating oil pump (not shown) was on the same side and driven in like manner. It supplied oil to the main bearings from the reservoir in the base of the crankcase. The oil returned to the reservoir by a small pipe, being filtered in passing. A sight tube was fitted to indicate the level.

Ignition was by means of a high-tension Eisemann magneto, driven from the forward end of the camshaft. The water for cooling the engine was circulated by a rotary pump (not shown), mounted on the forward end of the main shaft.

This engine has a free exhaust and has also auxiliary exhaust ports in the cylinders which are uncovered when the piston is at the end of its stroke.

The principal data are :—Weight, 240 lb. ; b.h.p., 30 ; normal speed, 1,450 r.p.m. ; bore, 112 mm. (4·4 in.) ; stroke, 100 mm. (3·93 in.). Inv. 1920–383.

7. 60 H.P. WRIGHT ENGINE, 1915. Lent by the Imperial War Museum.

This engine was designed by the Wright brothers, and is in all probability the example which was sent to the Beatty School of Flying, Cricklewood, in 1915, as a pattern from which the engines were made for use in the school machines.

It is a six-cylinder, vertical, water-cooled engine. Each cylinder is of cast iron with integral head, and welded sheet steel water jacket. The valves are located in the cylinder heads and are operated by vertical rods and rocker arms. The pistons are of cast iron, each fitted with three rings. The connecting rods are of H section chrome nickel steel. The crankcase is cast in two portions, with a removable side cover. A control is fitted for lifting the exhaust valves. Vaporization is assisted by water pipes from the cooling system which are coiled round the induction pipes.

The principal data are :—Bore, 4·375 in. ; stroke, 4·5 in. ; power, 60 h.p. at 1,400 r.p.m. ; fuel consumption, 0·56 pt. per h.p. hr. ; weight per h.p., 5·1 lb.

See *First Annual Repor tof the National Advisory Committee for Aeronautics*, 1915.

Inv. 1923–790.

## *BELGIAN*

8. 70 H.P. VIVINUS ENGINE, 1908–10. Presented by Messrs. Piggott Brothers & Co., Ltd.

This engine, of Belgian manufacture, is an example of the four-cylinder vertical type of engine adopted for aeroplane propulsion from orthodox automobile practice during the period 1908–10. The example shown was fitted in the Piggott experimental biplane of 1910, a similar engine being fitted in Henri Farman's first aeroplane, whilst a 50 h.p. example was used by Moore-Brabazon in December 1908.

The cylinders are of cast iron, cast in pairs and lightened by partially replacing the cast-iron water jackets with aluminium castings. The camshaft is carried in a separate box housing bolted to the crankcase, which in turn is a solid cylindrical aluminium casting with access to the interior by bolted end-flanges, also of aluminium. Inspection covers beneath the crankcase permit the detachment of the connecting rod big ends, the crankshaft being withdrawn through the end of the case. Ignition is by high-tension magneto (now missing), to single sparking plugs in the cylinder heads. Lubrication is under pressure from a pump, with outside leads to the cylinder walls and the crankshaft bearings. Cooling is by thermo syphon.

The principal data are :—Bore, 115 mm. (4·52 in.) ; stroke, 130 mm. (5·12 in.) ; power, 75 b.h.p. at 1,800 r.p.m. ; weight, dry, 280 lb. ; 3·8 lb. per h.p.

See Jane, *All the World's Aircraft*, 1910–11. *Flight*, April 10, 1909, p. 207 ; May 21, 1910, p. 383. Inv. 1929–829.

9. MAXIM'S EXPERIMENTAL PETROL ENGINE, 1908. Presented by Lady Maxim.

This four-cylinder engine was designed in 1908 by Sir Hiram Maxim for use in aeroplanes; it was constructed and tested in 1909–10, but was never used in actual flight. Reduction in weight was effected by the employment of German silver water jackets, overhead valve gear, and a sheet metal bottom for the crankcase.

The four vertical cylinders are held by eighteen long bolts. The heads are detachable and each contains two valves of large diameter which are mechanically operated by means of an overhead bevel gear-driven camshaft. The cylinders are fitted with water jackets and the heads and valve ports are cooled by the circulation of water in the casting from a circulating pump mounted at the rear of the engine. The carburetter (incomplete) was designed by Maxim to obtain an automatic regulation of the pressure and temperature of the fuel and of the air supplied. The jacketed induction manifold is warmed by water from the cooling system. Lubrication of the main bearings is by a circulator driven by a belt from the camshaft. The oil is fed by five leads to the crankshaft bearings and drip feed sights are provided. The cylinder walls and other parts of the engine are lubricated by splash from the crankcase. Inv. 1918–155.

10. 60 H.P. GREEN ENGINE, 1909–10. Lent by the Green Engine Co., Ltd., London, W.

This engine was entered for the Alexander Motor Prize Competition, 1911, and was awarded the prize of £1,000 offered by Mr. Patrick Y. Alexander. It embodies the patents taken out by Mr. G. Green and others in 1904–5.

The four cylinders, 140 mm. (5·5 in.) diam. by 146 mm. (5·85 in.) stroke, with their valve chambers, are separate steel castings, and are held down by lugs on the lower flanges of the cylinders. Copper water jackets are employed with a special joint at their lower ends; a groove on the cylinder contains a rubber ring, over which the jacket is forced by being slightly bell-mouthed, making a watertight joint while allowing free movement of the jacket.

The crank chamber is an aluminium casting, having a separate lower portion forming an oil sump attached to the casting by aluminium straps. At one end of the hollow crankshaft is a pair of gear wheels which drive the magneto and camshaft spindles.

The camshaft is arranged above the cylinders and is driven from the crankshaft by a vertical spindle at its end by a pair of bevel wheels at the top and the gear wheels at the bottom. The inlet and exhaust valves are mounted in cylindrical cages. The valves are operated by rocking levers pivoted on extensions of the camshaft casing. Auxiliary exhaust ports are provided in the cylinder walls just below the water jackets.

The carburetter is a Zenith. Lubrication is provided by a small gear wheel pump driven by an extension of the vertical spindle delivering oil under pressure to a passage cast in the upper part of the crank-chamber which communicates with each of the crankshaft bearings. Splash lubrication serves for the gudgeon-pins and pistons. Both the magneto and the water pump are driven by a transverse shaft that is skew-driven from the crankshaft.

This engine developed a mean b.h.p. of 62 in the first 12 hours' continuous run at 1,155 r.p.m., and a mean b.h.p. of 61·2 in the second 12 hours' continuous run at 1,145 r.p.m. Inv. 1913–427.

11. 35 H.P. GREEN ENGINE, 1909. Lent by the Imperial War Museum. (Shown mounted in the car of H.M.A. "Beta.")

This small four-cylinder, water-cooled engine was introduced about 1909, and was used successfully in many of the early aircraft, including the first Avro biplanes of 1911, and the non-rigid airship "Beta" of 1912. In 1918–19 the 35 h.p. Green engine was again put into production, but with slight modifications such as the substitution of aluminium pistons, and it was used in the "Baby" Avro biplanes, where it proved highly successful in competitions such as the Aerial Derby, and in the non-stop flight made by Mr. B. Hinkler from London to Turin.

The detail design is similar to that of the higher powered engines shown.

The principal data are:—Bore, 105 mm. (4·13 in.); stroke, 120 mm. (4·72 in.); weight, dry, 158 lb.; 4·5 lb. per h.p. Inv. 1923–1437.

12. SECTIONED 150 H.P. GREEN ENGINE, 1911. Presented by the Air Ministry.

The six-cylinder Green engine closely resembles the smaller four-cylinder type in design and construction.

The crankshaft is of chrome vanadium steel, with the cranks set at 180 deg. An improvement has been effected in the cooling system by the introduction of a new water-pipe joint at the inlet and outlet points of the cylinder jackets, flexible without rubber tubing by the use of a special rubber ring. The lubrication is forced, and the pressure has also been increased.

The principal data of the engine are :—Weight, 450 lb. ; b.h.p., 150 ; bore, 150 mm. ; stroke, 178 mm. ; speed, 1,250 r.p.m. ; inlet valve opens 4 mm. after t.d.c. closes 35 mm. after b.d.c. ; exhaust valve opens 20 mm. before b.d.c. and closes 2 mm. after t.d.c. ; ignition occurs 12 mm. before t.d.c. Inv. 1919–427.

13. 150 H.P. GREEN ENGINE, 1912–13. Presented by Claude Grahame-White, Esq.

This example contains several improvements on the sectioned example shown adjacent, which is of earlier date. The engine was in use on the Cody biplane on which the late Mr. S. F. Cody met his death in 1913.

The differences consist in the provision of auxilliary exhaust ports drilled round the base of the cylinders, and an additional oil pressure feed to each cylinder base with a pressure regulator and filter. Inv. 1927–1950.

14. 40 H.P. A.B.C. ENGINE, 1912. Lent by the Imperial War Museum.

This is an early type of four-cylinder, water-cooled engine, built by the All-British Engine Co. With one of these engines, in a Sopwith biplane, the late Mr. H. Hawker beat the British duration record and won the Michelin Cup in 1912. Some parts of the engine are now missing. Copper water jackets are employed. There is one inlet and one exhaust valve fitted in the head of each cylinder, being operated by push rods from the camshaft which is situated in the crankcase. Forced feed lubrication by pump is employed.

The principal data are :—Bore, 95 mm. (3·74 in.) ; stroke, 80 mm. (3·15 in.) ; speed, 1,450 r.p.m. ; weight, 155 lb. ; power, 30 b.h.p. ; weight per h.p., 5·17 lb.

See Jane, *All the World's Aircraft*, 1913, p.3c. Inv. 1923–777.

15. 120 H.P. BEARDMORE AUSTRO-DAIMLER ENGINE, 1912. (Shown mounted in Cody biplane.)

This is a dummy engine showing the cylinders and crankcase of the 120 h.p. model, from which the 160 h.p. model was developed during the war period. The design is exactly similar except for the greater cylinder capacity provided for in the latter engine. Inv. 1913–136.

16. SECTIONED 160 H.P. BEARDMORE ENGINE, 1915. Presented by Messrs. Wm. Beardmore & Co., Ltd.

This is a six-cylinder, vertical, water-cooled engine manufactured by Messrs. Arrol-Johnstone, Ltd., an automobile firm associated with the donors. Arrangements were made with the Austro-Daimler Co. about 1912 for the manufacture of their engines in Britain, the Beardmore engine being at first a duplicate of the original design ; by 1915 the power of the standard 120 h.p. engine was increased to 160 h.p.

Single overhead inlet and exhaust valves are fitted in each cylinder, and are operated by single rods from the crankcase by the Parsch patented system of rocking lever. The cylinders are off-set 18 mm., and are copper water-jacketed. Two Zenith carburetters supply the explosive mixture to the cylinders, and ignition is effected by two H.T. magnetos.

The principal data are :—B.h.p., 166 at 1,250 r.p.m. ; bore, 142 mm. ; stroke, 175 mm. ; weight, 600 lb. ; petrol consumption, 0·57 pt. per h.p. hr.
Inv. 1924–671.

17. 100 H.P. ROLLS-ROYCE "HAWK" ENGINE, 1915. Lent by the Imperial War Museum. (Shown mounted in the car of the "S.S.Z." type airship.)

The "Hawk," which is a six-cylinder, vertical, water-cooled engine, is an early aero-engine produced by the Rolls-Royce Co. The cylinders are separate castings with welded steel water jackets, and represent the standard Rolls-Royce system of construction. The crankcase is split along the crankshaft centre, the lower portion being designed on the dry sump system with oil scavenging pump.

The principal data are :—Bore, 4 in. ; stroke, 6 in. ; b.h.p., 100 at 1,500 r.p.m. ; maximum permissible speed, 1,700 r.p.m. ; fuel consumption, 6·5 gall. per hr. ; oil,

0·5 gall. per hr.; weight, dry, 405 lb.; amount of water carried in jackets and piping, 1·4 gall.

See Jane, *All the World's Aircraft*, 1919, p. 129b. Inv. 1923–1444.

18. 200 H.P. B.H.P. ENGINE, 1917.

This vertical, six-cylinder, water-cooled engine was developed by the Siddeley Deasy Motor Co., Ltd., Coventry.

Each cylinder block casting comprises the cylinder heads, water jackets, valve passages, and inlet manifold of three cylinders, into which steel liners are fitted forming the working barrels. Near the level of the combustion chamber the jackets are divided horizontally into two portions which are bolted together Leakage is prevented at the base of the aluminium jacket by means of a rubber ring pressed against a shoulder of the steel liner by a castellated ring-nut screwed into the jacket.

The cylinder heads are flat and each carries a large nickel steel inlet valve, and two smaller tungsten steel exhaust valves, all operated by a single hollow camshaft, the exhaust valves being operated directly and the inlet valves through the agency of a small rocking lever.

The pistons are die cast from an aluminium alloy and each carries three cast-iron rings near the head, and a scraper ring in the skirt. High tensile steel connecting rods, machined to H-section connect with the six-cylinder seven-bearing type crankshaft, the cranks of which are spaced 120 deg. apart.

The crankcase is in two portions, the upper portion, which is stiffened by cross-webs, is formed integral with the housings of the crankshaft bearings, and carries the eight supporting feet of the engine, in addition to the main lubrication filter and two breathers. The lower half acts as an oil sump and a cover for the moving parts, and is furnished with sharply inclined gutters which ensure that the filter remains constantly submerged in oil. Lubrication is by means of two pumps, driven by a vertical shaft which operates the whole of the accessories. The upper pump draws oil from an external tank and forces it by way of a filter into a manifold, which, by means of branch pipes, supplies oil to the journal bearings, the thrust housing, the vertical shaft and the skew gearing operating the magnetos. Oil fed to the main crankshaft bearings, passes into the hollow journals, and by way of holes drilled in the crank-webs, to the crank-pins, whence it is flung on to the cylinder walls and the small ends of the connecting rods. From the front end of the manifold a small pipe conveys oil through the hollow camshaft to the camshaft bearings, whence it is flung on to the cams, rocking levers, and valve heads. Oil which collects in the base of the chamber is drawn out by the second pump and delivered back to the oil tank.

Two independent sparking plugs are fitted in each cylinder, one set being connected to a Fellows E.M.6 type magneto, the second set being served by a small six-volt battery, through a Rémy combined contact breaker and distributor mounted at the rear end of the camshaft housing, and a coil carried on the other magneto platform. Two Zenith carburetters are fitted.

The principal data of the engine are :—Normal b.h.p., 246; maximum b.h.p., 255; bore, 145 mm.; stroke, 190 mm.; normal r.p.m., 1,400; weight (without cooling water), 625 lb.; oil consumption, 1·8 gall. per hr.; petrol consumption, 17 gall. per hr.; order of firing, 1, 5, 3, 6, 2, 4; valve timing, inlet valve opens 7 deg. after t.d.c. and closes 43 deg. after b.d.c.; exhaust valve opens 58 deg. before b.d.c. and closes 12 deg. after t.d.c.; ignition occurs at maximum advance, 37½ deg. before t.d.c.

See *Aeronautics*, March 27, 1919. Inv. 1920–48.

19. 75–85 H.P. "CIRRUS" MARK II. ENGINE, 1925. Lent by Messrs. A. D. C. Aircraft, Ltd.

This four-cylinder, air-cooled engine is a modification of the earlier "Cirrus" engine which was produced to meet the requirements of the light aeroplane constructor, and was the first low-powered aero-engine to pass the Air Ministry 100 hours' type test.

The cylinders, which are of cast iron and provided with cooling fins, and the aluminium alloy heads, are secured to the crankcase by four long studs passing through lugs on the cylinder heads. The valves are of the overhead type, operated through rockers by push rods from the camshaft, which is supported on three plain phosphor bronze bearings. The trunk type pistons of aluminium alloy are each fitted with three cast-iron rings. The gudgeon pin is a floating fit on the piston, and is fixed in the H-section connecting rod by a special stud and nut. The crankshaft, of usual four-throw type, is carried in five bearings, the three inner being of white metal with phosphor

bronze shells, the front and rear being of ball-bearing type. The upper half of the crankcase carries the three phosphor bronze crankshaft bearings and the top half of the ball-bearing housings, also the camshaft. The lower portion forms the oil sump and carries the oil pump relief valve and oil strainer, and also forms the lower half of the ball-bearing housings. Two 4-cylinder B.T.H. magnetos, giving dual ignition, and one Zenith type F.S. 42 carburetter, are fitted.

The principal data are :—Bore, 110 mm. (4·33 in.) ; stroke, 130 mm. (5·12 in.) ; compression ratio, 4·9/1 ; weight dry, 280 lb. ; power, 75 b.h.p., at 1,800 r.p.m. ; 80 b.h.p. at 2,000 r.p.m. ; fuel consumption, 0·6 pt. per h.p. hr. ; oil consumption, 0·019 pt. per h.p. hr. Inv. 1929–84.

## *GERMAN*

20. SECTIONED 180 H.P. ZEPPELIN-MAYBACH AIRSHIP ENGINE, 1915. Presented by the Lords Commissioners of the Admiralty.

This is a type of Maybach engine designed primarily for use in the Zeppelin airships. It resembles the later types in general design, but is not fitted with overhead valves. The most noteworthy details of construction are the design of carburetter, the water circulating pump, the oil circulating pump and pulsator, the automatic magneto advance and the special starting apparatus.

The engine has six vertical cylinders, with four valves in each. The carburetters, of which there are two, have been designed to dispense with a float chamber and to work in conjunction with a petrol-pump system. The throttle is of the rotary-barrel type ; it is connected with a sliding shutter, which controls the air which flows past the jets, and with a rotatable cover which regulates their size. The petrol level in the adjoining vessel is kept constant by a pump (not shown), an overflow pipe returning the excess to the tank. The water circulating pump is of the helical type, having a rotating impeller between two stationary castings formed with helical passages leading in a reverse helical direction to the impeller.

Oil is circulated to the main bearings by means of a plunger pump mounted vertically. A scavenger pump of the gear type is fitted at the end of the crankcase ; the oil leads are not shown. Ignition is by means of two H.L.6 Bosch magnetos, which are driven by bevel gearing and a mechanism which gives an automatic advance of the firing point. A " tell-tale " mechanism is fitted at the end of the magneto driving shaft. An electric circuit is closed when the revolutions reach a critical speed or when the pressure in the oil-circulating system is reduced. The Maybach starting apparatus is of special interest. The necessity for turning the engine over preliminary to starting is avoided by the use of a mechanism which lifts all the valves and permits an explosive charge to be drawn into the cylinders by means of a suction pump. This is accomplished by lifting all the tappets off their cams by means of a hand lever, which rotates two lay shafts engaging with small lugs projecting from the tappets ; at the same time a shutter in the exhaust main is closed. A hand pump (not shown) is then operated and an explosive mixture is sucked from the carburetter through the cylinders to the exhaust manifold and pump. When the cylinders are thus charged the lever is brought vertical, which restores the engine to its operating position, and the starting magneto is used.

The principal data are :—Bore, 160 mm. (6·3 in.) ; stroke, 170 mm. (6·69 in.) ; ratio, bore to stroke, 1·06 ; r.p.m., 1,200 ; piston speed, 1,340 ft./min. ; weight, dry, 990 lb. ; weight, per h.p., 5·5 lb. ; normal power, 180 h.p. Inv. 1919–426.

21. 300 H.P. MAYBACH ENGINE, 1917. Presented by the Air Ministry.

This is a six-cylinder, vertical, water-cooled engine designed for use in aeroplanes.

Each cylinder is built up of a thin steel barrel into the top of which is screwed the cast-iron cylinder head, in which the valve guides are fitted with cast-iron bushes pressed into position. The water jackets are machined from cylindrical steel forgings, which are screwed on to a flange machined on the cylinder head, and extend for about two-thirds of the length of the cylinder barrel.

The pistons are of cast iron with four piston rings above the gudgeon-pin, the lower one being a scraper ring, while an oil groove is cut on the piston skirt below the gudgeon-pin. The connecting rods, which are of square section, bevelled at the four corners and bored up the centre from the big end, connect with an ordinary six-throw crankshaft, an extension at the rear end of which carried the wireless dynamo driving pulley, which embodies a friction clutch.

The aluminium crankcase is cast in two portions, the upper of which supports the crankshaft main bearings by bolts which also serve to bolt down the cylinders. The lower part of the crankcase carries the small detachable oil sumps, together with the three oil pumps. The oil is delivered under pressure from the rearmost pump to the crankshaft journal bearings through an external oil main along the exhaust side of the engine, and is fed to the journal bearings through oil ways drilled diagonally in the crankcase casting through the transverse webs. Oil scoops bolted to the outer sides of each crank web serve to collect the oil which is forced through the journal bearings, and in this way lubricate the crankpins and small end bearings.

The two scavenger pumps, situated one at either end of the base chamber, draw off the oil from the sumps, and return it to the tank. Two Bosch Z.H.6 magnetos are provided and effect dual ignition, two plugs being fitted in the head of each cylinder.

The principal data of the engine are :—Bore, 165 mm. (6·5 in.) ; stroke, 180 mm. (7·09 in.) ; ratio, bore to stroke, 1·09 ; compression ratio, 5·94 ; weight, dry, 911 lb. ; weight per h.p., 3·1 lb. ; b.h.p., 294 ; r.p.m., 1,400 ; petrol consumption, 20 gall. ; oil consumption, 11 pt. ; order of firing, 1, 5, 3, 6, 2, 4 ; inlet valve opens 8 deg. before t.d.c., closes 35 deg. after b.d.c. ; exhaust valve opens 33 deg. before b.d.c., closes 7 deg. after ; magneto advance, 38 deg. before t.d.c.

A full description and test of this engine will be found in Jane, *All the World's Aircraft*, 1919, p. 93b. Inv. 1920–355

22. 260–300 H.P. MAYBACH ENGINE, 1917–18. Lent by the Air Ministry.

This engine represents the last Maybach design produced during the war (1914–18), and is of the Type Mb IVa, arranged for installation in an aeroplane. Each cylinder is separate, consisting of a thin steel barrel into which is screwed the cast-iron head, into which the valve guides, cast-iron bushes, are pressed.

The steel water jackets are screwed to a flange on the cylinder head. The pistons, of cast-iron, carry four rings above the gudgeon-pin. The connecting rods are of square section with bevelled corners, and are bored up their centres from the big end.

The aluminium crankcase is made in two portions : the upper carries the crankshaft bearings by bolts, which also hold down the cylinders by triangular clamps ; the lower serves as a base chamber, with detachable oil sumps, and contains three oil pumps. The oil is fed under pressure from the rearmost pump to the journal bearings, through an arterial system, whilst oil scoops bolted to the outer sides of each crank web, collect the oil forced through the bearings and lubricate the crankpins and small end bearings. The two scavenger pumps, situated at either end of the base chamber, draw off the used oil from the sumps and deliver it to the tank. Two Bosch Z.H.6 type magnetos supply dual ignition, with two sparking plugs per cylinder.

The principal data are :—Bore, 165 mm. (6·5 in.) ; stroke, 180 mm. (7·09 in.); compression ratio, 5·94 : 1. Speed and power :—

| | | | *Normal.* | |
|---|---|---|---|---|
| R.p.m. .. .. .. .. | 1,200 | 1,300 | 1,400 | 1,500 |
| B.h.p. .. .. .. .. | 258 | 279 | 294·5 | 304·5 |
| Brake m.e.p. .. .. .. | 120·5 | 120·3 | 118 | 113·9 |
| Fuel consumption, pints per h.p. hr. | 0·53 | 0·52 | 0·526 | 0·545 |
| Oil consumption, pints per h.p. hr. | — | — | 0·038 | — |

Weight, 911 lb. ; 3·1 lb. per h.p.

This engine is very fully described and illustrated in Jane's *All the World's Aircraft*, 1919, pp. 93b to 102b. Inv. 1921–508.

23. SECTIONED 160 H.P. MERCEDES ENGINE, 1915–16. Lent by the Imperial War Museum.

This engine is of the six-cylinder, vertical, water-cooled type, and is the forerunner of the 180 and 200 h.p. Mercedes engines.

The steel cylinders are cast in single units, with integral water jackets. The overhead valves are operated by an overhead camshaft which is bevel driven from the crankshaft. Twin-jet dual carburetters, enclosed in a cast-aluminium water jacket supply the explosive mixture to the cylinders. Each carburetter feeds three cylinders through a branched steel induction pipe. Two Bosch magnetos are fitted, and forced feed lubrication is adopted.

The principal data are :—Bore, 140 mm. (5·52 in.) ; stroke, 160 mm. (6·3 in.) ; ratio, bore to stroke, 1·14 ; r.p.m., 1,250 ; compression ratio, 4·8 ; weight, dry, 618 lb. ; weight per h.p., 4·12 lb. Inv. 1923–751.

24. 180 H.P. MERCEDES ENGINE, 1916. Presented by the Air Ministry.

This six-cylinder, vertical, water-cooled engine is a modification of the earlier 160 h.p. model.

The steel cylinders, which are built up separately, have the valve pockets screwed and welded into the cylinder heads and the water jackets, of pressed sheet steel, welded in position. The pistons, which are machined from steel forgings, have concave heads and cast-iron skirts and are provided with three rings. H-section connecting rods, with floating cast-iron gudgeon-pin bushes, connect with crankshaft. The crankcase is cast in two halves, the lower portion being cast integral with the lower half of the main bearing housings.

The single inlet and exhaust valves of each cylinder are interchangeable and set at an angle of 15 deg. The camshaft casing is constructed entirely of malleable iron castings, and the steel valve rocker spindles work in direct contact with the malleable iron, and the covers of the camshaft casing form the top portion of the rocker spindle bearings. The rocker spindles are hollow and are lubricated through two holes drilled radially in the spindles by oil thrown off the revolving cams into the two holes drilled in the rocker arm carrying the cam roller.

Explosive mixture is supplied to the cylinders by twin-jet dual carburetters, both carburetters being enclosed in a cast-aluminium water jacket. Each carburetter feeds three cylinders through a branched steel induction pipe lagged with asbestos, and ignition is effected by two Z.L.6 type Bosch magnetos, driven directly off the camshaft vertical driving shaft by bevel gears.

The principal data of the engine are :—Weight, 635 lb. ; normal b.h.p., 174 ; normal speed, 1,400 r.p.m. ; bore, 140 mm. ; stroke, 160 mm. ; compression ratio, 4·64 : 1 ; petrol consumption, 12·5 gall. per hr. ; oil consumption, 7·3 pt. per hr. ; order of firing, 1, 5, 3, 6, 2, 4 ; ignition timing (fully advanced), 30 deg. before t.d.c. ; inlet valve opens at t.d.c. and closes 40 deg. after b.d.c. ; exhaust valve opens 40 deg. before b.d.c. and closes 10 deg. after t.d.c.

See Jane, *All the World's Aircraft*, 1918, p. 57d. Inv. 1920–354.

25. 240 H.P. MERCEDES ENGINE, 1917. Lent by the Imperial War Museum.

Differing from the usual Mercedes practice this vertical, water-cooled engine has eight cylinders. It was fitted to an Albatross aeroplane, but was more generally used for airship propulsion.

The overhead valves are operated by an overhead camshaft driven through a vertical shaft from the crankshaft, and a reduction gear is fitted between the airscrew and the engine giving a ratio of 1·382 : 1. Two carburetters supply the explosive mixture to the cylinders, each carburetter feeding four cylinders through large copper induction manifolds.

The engine weighs 3·72 lb. per h.p., the bore is 140 mm. and the stroke is 160 mm.

Inv. 1923–779.

26. 230 H.P. BENZ ENGINE, 1917. Presented by the Air Ministry.

Following the usual German aero-engine practice, this engine is of the six-cylinder vertical, water-cooled type.

Each separate cylinder is bolted to the crankcase by long studs, which pass through the top half of the crank-chamber and secure the crankshaft bearings between the top and bottom halves of the crank-chamber. Two inlet and two exhaust valves are fitted in the head of each cylinder, and are operated by overhead valve rockers and by push rods on either side of the cylinders. The two camshafts, which run on plain bearings, are neatly arranged inside of the top half of the crankcase, and the floating exhaust camshaft is provided with half-compression cams. The pistons are of cast iron, fitted with three exceptionally wide rings, and the piston heads are supported by conical steel forgings riveted and welded to the piston crowns, which bear on the centre portion of the gudgeon-pins, through slots cut in the connecting rod small ends.

Two separate two-jet carburetters are fitted, having their intake passages through the top half of the crankcase casting, and each supplying three cylinders through an independent branched induction pipe, built up of light aluminium tube.

The lubrication of the crankshaft and connecting rod bearings is effected by a gear pump working in an auxiliary oil reservoir formed in the bottom of the air-cooled base chamber. An oil-sealed petrol pump driven off the rear end of the inlet camshaft supplies petrol to the carburetters in conjunction with a supplementary pressure reservoir enclosed in the main petrol tank.

The principal data are :—Weight, 848·5 lb. ; b.h.p., 230 ; normal speed, 1,400 r.p.m. ; bore, 145 mm. ; stroke, 190 mm. ; compression ratio, 4·91 : 1 ; petrol consumption, 18·75 gall. per hr. ; oil consumption, 4·5 pt. per hr. ; order of firing, 1 5, 3, 6, 2, 4 (the cylinders being numbered consecutively from the airscrew end) ;

inlet valve opens 10 deg. before t.d.c. and closes 55 deg. after b.d.c.; exhaust valve opens 60 deg. before b.d.c. and closes 20 deg. after t.d.c.; ignition occurs 30 deg., or 18 mm. before t.d.c.

See Jane, *All the World's Aircraft*, 1919, p. 35b. Inv. 1920–356.

27. 180 H.P. OPEL ARGUS ENGINE, 1917. Presented by the Air Ministry.

The Opel Argus engine is of the six-cylinder vertical, water-cooled type, and was produced in large quantities during the last two years of the war.

The cylinders are arranged in three pairs mounted as separate units, with a common water jacket. The cylinder heads are flat and integral with the cylinder barrels.

In each cylinder block the two inlet valves are situated innermost, with their pockets opening to one side of the engine, while the two exhaust valves are outermost and deliver to a manifold on the opposite side.

In the early forms of this engine cast-iron pistons were employed, but, later, aluminium pistons were fitted. The connecting rods are of the normal H-section, but with the big and small ends offset in opposite directions. The crankshaft is of the six-throw unbalanced type and runs in seven white-metalled, phosphor-bronze bearings, housed between the upper and lower halves of the crankcase. The throws and journals are hollow and are closed by discs forced into recesses machined therein. The crankcase is of aluminium alloy and is divided into a horizontal plane through the axis of the crankshaft, the two halves being secured together by a flanged joint and numerous bolts, and also by 16 supporting studs. Dome-headed poppet valves are employed for both inlet and exhaust valves, which are operated by a camshaft carried in the upper half of the crankcase. The cylinders are served by two Zenith Opel carburetters, each of which serves three cylinders by a separate manifold. A compound oil pump fitted in the base of the sump is of the plunger type and consists of four pumps built as a unit, to pressure feed the crankshaft bearings and to act as feed pump and scavenge pump.

Ignition is effected by two six-cylinder Z.H.6 type Bosch magnetos, which are strapped to platforms cast on the crankcase.

The principal data of the engine are:—Weight, 756 lb.; normal b.h.p., 180; normal speed, 1,400 r.p.m.; bore, 145 mm.; stroke, 160 mm.; petrol consumption, 14·75 gall. per hr.; oil consumption, 3 pt. per hr.; order of firing, 1, 5, 3, 6, 2, 4; inlet valve opens 12 deg. before t.d.c. and closes 80 deg. after b.d.c.; exhaust valve opens 66 deg. before b.d.c. and closes 13 deg. after t.d.c.

See Jane, *All the World's Aircraft*, 1919, p. 12b. Inv. 1920–358.

28. 270 H.P. BASSE AND SELVE ENGINE, 1917. Lent by the Imperial War Museum.

This is a six-cylinder, vertical, water-cooled engine of German design and was fitted to a Rumpler biplane.

Two inlet and two exhaust valves inclined at 23·5 deg. to the vertical are fitted in the head of each cylinder, and are operated by an overhead camshaft driven through a vertical shaft. The pistons are of aluminium and the crowns are considerably domed; the compression, however, is only 4·34 : 1.

The explosive mixture is supplied by two separate two-jet carburetters, each feeding three cylinders, and ignition is effected by two Bosch Z.H.6 magnetos driven obliquely to the crankshaft axis by bevel gear from the camshaft driving spindle.

The principal data are:—Bore, 155 mm. (6·11 in.); stroke, 200 mm. (7·88 in.); ratio, bore to stroke, 1·29; r.p.m., 1,400; compression ratio, 4·34; weight, dry, 885 lb.; weight per h.p., 3·28 lb.

This engine is fully described in Jane, *All the World's Aircraft*, 1919, p. 27b.

Inv. 1923–770.

29. 225 H.P. AUSTRO-DAIMLER ENGINE, 1917. Lent by the Imperial War Museum.

This engine is of the six-cylinder, vertical, water-cooled type. It has separately built-up steel cylinders.

Two inlet and two exhaust valves are fitted in each cylinder head, and are operated by an overhead camshaft driven by a vertical shaft from the front end of the crankshaft. The pistons are of aluminium and heavy H-section connecting rods are fitted.

A water-jacketed duplex carburetter supplies the explosive mixture to the cylinders through two separate steel induction manifolds, and ignition is effected by two Bosch Z.H.6 magnetos driven obliquely from the vertical shaft. The magneto and throttle controls are inter-connected, so that ignition is automatically retarded when throttling down.

The principal data are :—Bore, 135 mm. (5·31 in.) ; stroke, 175 mm. (6·9 in.) ; ratio, bore to stroke, 1·3 ; normal b.h.p., 200 at 1,400 r.p.m. ; maximum, 222 h.p. at 1,600 r.p.m. ; compression ratio, 5·02 ; weight, dry, 720·5 lb. ; weight per h.p., 3·64.

See Jane, *All the World's Aircraft*, 1919, p. 14b. Inv. 1923–815.

## *ITALIAN*

30. 150–160 H.P. ISOTTA-FRASCHINI V.4.B. ENGINE, 1915. Presented by **the Italian Government.**

This is a six-cylinder, vertical, straight-line engine made by La Fabrica Automobili Isotta-Fraschini, of Milan, and extensively used during the war (1914–18), and afterwards on Italian service and commercial aircraft.

The cylinders are formed in pairs with sheet brass water jackets, attached by a series of small screws. Forced lubrication under pressure is employed to distribute the oil to all bearings, big ends, and the camshaft housing. The crankcase is of aluminium, arranged on the dry sump system, and split along the crankshaft centre line, the oil return and pressure pumps, together with the water-circulating pump, being mounted at the rear end. The valves, of which there are one exhaust and one inlet valve per cylinder, are operated by an overhead camshaft which is driven by a vertical shaft from the rear end of the crankshaft. Each pair of valves is held on to their seatings by a single central spring, pressing against the underside of a beam, the ends of which are entered into slots in the valve stems.

The cams and cam rollers and levers are enclosed, but the valve-operating levers are exposed. The compression pressure can be relieved for starting by pressing the whole camshaft endwise by a hand lever, so as to bring small relieving cams into operations. Dual ignition is provided by two Marelli six-spark magnetos firing separate plugs situated on opposite sides of the cylinder heads. Mixture is supplied by two independent Zenith carburetters, each feeding three cylinders.

The principal data are :—Bore, 5·1182 in. (130 mm.) ; stroke, 7·0867 in. (180 mm.) ; h.p., 150–160 at 1,200 to 1,300 r.p.m. ; at a later date the power was increased to 190 h.p. at 1,450 r.p.m. ; weight, 561 lb. ; weight per h.p., 2·95 lb. ; overall length, 5 ft. ; height, 3·25 ft. ; width, 2·3 ft. ; petrol consumption, 0·551 lb. per h.p. hr. ; oil, 0·043 lb. per h.p. hr.

See Jane, *All the World's Aircraft*, 1916–24. *Flight*, 1918, p. 94.

Inv. 1927–814.

31. 260 H.P. ISOTTA-FRASCHINI V.6 ENGINE, 1918–19. Presented by the Italian Government.

This engine is a development of the V.4.B. type shown adjacent, and is made by La Fabrica Automobili Isotta-Fraschini, of Milan. The arrangement is generally similar to the smaller example, but the end silhouette has been considerably reduced permitting of a more efficient form of aircraft body to accommodate the engine.

The cylinders are formed in pairs with sheet brass, screw attached, water jackets. Forced lubrication is provided, the oil-circulating and return pumps together with the water-circulating pump being mounted at the rear end of the crankcase, which is of the dry sump type and split along the crankshaft axis.

The overhead camshaft, valves, and valve-operating mechanism are all enclosed in an overhead casing lubricated from the pressure system. The compression can be relieved for starting by moving the camshaft endwise by a hand lever, in order to bring relieving cams into operation.

Dual ignition is provided by two Marelli magnetos, each firing separate plugs situated at opposite sides of the cylinder heads.

The principal data are :—Bore, 5·5119 in. (140 mm.) ; stroke, 7·0867 in. (180 mm.) ; h.p., 260 at 1,700 r.p.m. Inv. 1927–815.

32. 200 H.P. S.P.A. ENGINE, 1917. Lent by the Imperial War Museum.

This is a six-cylinder, vertical, water-cooled engine of Italian design, built by the Societa Piemontese Automobili of Turin.

Overhead valves are fitted in the head of each cylinder, and are operated by an overhead camshaft driven through a vertical shaft. The explosive mixture is supplied by two Zenith carburetters, and ignition is effected by two N.2 Marelli magnetos.

The principal data are :—B.h.p., 220 at 1,600 r.p.m. ; bore, 5·31 in. ; stroke. 6·69 in. ; lubrication, forced feed. Inv. 1923–804,

33. 300 H.P. F.I.A.T. ENGINE, 1919. (TYPE A.12 BIS.) Presented by the Italian Government.

This is a six-cylinder aero-engine of Italian design manufactured by the Societa Anonyma F.I.A.T. of Turin, subsequent to 1918. It represents a type of engine developed largely in the country of its origin and used with considerable success on various aircraft.

The separate cylinders are made wholly of steel and are each supplied with four valves slightly inclined in respect to the cylinder axis and operating in bronze bushes. These valves are operated from a single overhead camshaft enclosed in a bronze casing. The camshaft is driven by two pairs of bevel gears and a vertical shaft which is supported by ball races. The pistons are of a special aluminium alloy and are provided with four cast-iron rings at the upper part and one in the skirt. Gudgeon-pins are of hardened and ground steel and have large supporting surfaces. The crankshaft is of chrome nickel steel and revolves in white-metalled bronze bearings. A double carburetter is fitted, each jet feeding a group of three cylinders. Lubrication is effected by the distribution of oil under pressure.

The principal data are :—Bore, 160 mm.; stroke, 180 mm.; full speed, 1,600 r.p.m.; normal corresponding power, 300 h.p.; maximum speed, 1,800 r.p.m.; normal corresponding power, 320 h.p. Inv. 1927–812.

34. 110 H.P. "COLOMBO" ENGINE. Presented by the Italian Government.

This is a six-cylinder vertical engine made by the Construzioni Meccaniche Nazionali of Milan.

The cylinders are formed in pairs with screw attached sheet metal water jackets, the crankcases and overhead camshaft casing being aluminium castings. The general design is of the typical straight line, dry sump type, the crankcase being split along the crankshaft centre line, the lower half carrying the oil return and pressure circulating pumps at the rear end.

The valve arrangement is of the overhead type, there being one exhaust and one inlet valve per cylinder, operated by overhead tappet levers Dual ignition is provided by two Marelli magnetos firing separate sparking plugs at opposite sides of the cylinder heads, the magnetos being set at right angles to the crankshaft and driven by a cross shaft from the vertical shaft which drives the overhead camshaft. Mixture is supplied by a twin jet Zenith carburetter, two independent intake pipes supplying three cylinders each. A portion of the intake pipes is jacketed and supplied with hot-water heating.

The principal data are :—H.p., 110 at 1,350 r.p.m.; weight, dry, 495 lb.; weight per h.p., 4·5 lb. Inv. 1927–813.

## VEE TYPE ENGINES

### *AMERICAN*

35. 90 H.P. CURTISS ENGINE (MODEL O.X.5), 1915.

The engine here exhibited is a typical example of the various types produced by the Curtiss Motor Co., and used largely in U.S.A.

It is an eight-cylinder V-type water-cooled engine divided into two groups of four cylinders set at 90 deg.

The cast-iron cylinders, which are cast separately, are each attached to the crankcase by eight short studs and four long through bolts, the latter being secured at the top to a yoke fitting over the cylinder heads. The cast-iron valves having electro-welded steel stems are located in the cylinder heads, and are operated by push rods and rocker arms from a single hollow camshaft in the crankcase between the cylinders, the push rods operating the exhaust valves being within tubular push rods operating the inlet valves. The valves, guides, and seats are cast integral with the cylinders and the combustion chamber is nearly hemispherical. The water jackets are made of "monel," a non-corrosive combination of nickel and copper, and are oxy-acetylene welded to the cylinder walls, the whole of the cylinder and jacket being nickel plated. The cooling water is circulated by means of a centrifugal pump, mounted on an extension of the crankshaft projecting through the crankcase.

Lubrication is effected by means of a force pump driven by bevel gearing from a wheel formed integral with the crankshaft. The pump forces oil through the crankshaft to the five main bearings, and through the camshaft to the latter's bearings,

while oil slingers are fitted at each end of the crankshaft. The lower half of the crankcase is divided into four compartments, which serve as an oil reservoir, having a capacity of six hours' flight. The Berling D. 81 magneto is mounted between the cylinders and is driven from the camshaft gearing. A Schebler carburetter is fitted.

The principal data of the engine are :—Normal b.h.p., 90 ; weight, 325 lb. ; bore, 4 in. ; stroke, 5 in. ; normal speed, 1,200 r.p.m. ; maximum speed, 1,450 r.p.m. ; petrol consumption, 7 gall. per hr. ; oil consumption, 0·25 gall. per hr. The order of firing of the cylinders is 1, 2, 3, 4, 7, 8, 5, 6 ; inlet valve closes 0·406 in. after b.d.c. ; exhaust valve opens 0·6875 in. before b.d.c. Ignition occurs when fully advanced 0·5 in. before t.d.c.

**Inv. 1920–43.**

36. 400 H.P. "LIBERTY" ENGINE, 1917. Lent by the Air Ministry.

The design of the "Liberty" engine was determined in June 1917 by a committee of leading automobile and aircraft engineers of U.S.A., amongst whom were Mr. Hall of the Hall-Scott Co., Mr J. G. Vincent, of the Packard Motor Co., and Mr. Glen H. Curtiss and Mr. C. M. Manley of the Curtiss Co. The first engine was stated to have undergone test bed runs of 10 and 50 hours by October 1917.

The design is composite, the features considered most desirable for reliability and ease of mass production being incorporated from all available existing designs. It is a twelve-cylinder "V" engine, consisting of two banks of six cylinders set at an included angle of 45 deg. Separate cylinders of drawn steel are bolted to the top faces of the crankcase by a flange, the cylinder barrel projecting some distance into the case. The water jackets are formed of steel pressings, welded up, and to the cylinder.

The valves, one exhaust and one inlet per cylinder, are mounted in the heads, and included at 15 deg. to the centre line, the seatings being machined in the metal of the head, phosphor-bronze stem guides being pressed in. The camshafts, tappet levers, and bearing housings are mounted over the heads, and are driven by inclined shafts with bevel gear from a vertical shaft, driven from the rear end of the crankshaft, this shaft also carrying the ignition generator, whilst a second vertical shaft, below the first and driven by the same gear wheel, drives the oil pumps and water pump.

The intake manifolds are carried between the banks and are served by two duplex Zenith carburetters, giving separate carburation to the four groups of three cylinders. The pistons are of aluminium of a thick and un-ribbed section, 0·5 in. thick at the head and rings, tapering to 0·25 in. at the bottom of the skirt, each carrying three rings near the top, and provided with seven oil grooves. Two types of piston are provided, those for Army aircraft giving a compression space volume of 18 per cent of the displacement, whilst the engines for Navy aircraft give a 20·5 per cent volume. The pistons are 5 in. in length. The connecting rods are of H-section, 12 in. between centres, and are arranged in pairs, one solid and one forked to each crankpin. The gudgeon-pins are tubular, and a driving fit in the piston. The crankshaft is a drop forging with six throws at 120 deg., 2·625 in. diam., with seven bearings, all running in white metal lined bearings. The throws and bearings are all bored out, and the cheeks drilled for oil passages to the bearings. The shaft bearings are carried in halves by the aluminium crankcase castings.

Lubrication is on the dry sump system, two gear wheel pumps being provided, the upper one consists of three gears and draws surplus oil from sumps at each end of the crankcase, delivering this oil to the reservoir tank, the lower pump receiving this cooled oil and distributing it under pressure to all crankshaft and camshaft bearings, tappets, and cams, the surplus lubricating the driving gears on its way back to the sump. The cylinder walls and gudgeon-pin are splash oiled. Ignition is by the Delco system, consisting of a generator and floating battery, with duplicated contact breakers, and distributors, the latter being mounted on the ends of the camshafts. The batteries supply current up to 650 r.p.m., when the generator builds up and takes the whole load.

The principal data are :—Bore, 5 in. ; stroke, 7 in. ; total piston displacement, 1,649·34 cu. in. ; piston speed, 1,980 ft. per min. ; weight, approx. 806 lb. ; power, 350–400 b.h.p. with high, and 320–340 b.h.p. with low-compression pistons, at normal speed. Rated fuel consumption, 0·54 lb. per b.h.p. hr., or 36 gall. per hr., at full throttle and 1,700 r.p.m. ; about 30 gall. per hr. in normal flight ; oil consumption, 0·03 lb. per h.p. hr., or 1·5 gall. at full throttle. Normal r.p.m., 1,700 in horizontal flight, or 1,600–1,625 on the ground ; oil pressure, up to 50 lb. per sq. in. ; water capacity of engine, 5·5 gall.

For fuller particulars, see *Flight*, June 16, 1918, p. 650. (A full description of the origin and compromises of design.) Jan. 2, 1919, p. 6. (A full technical description, with sectional drawings.) Feb. 13, 1919, p. 201. (Technical tables.) Aug. 14, and Sept. 4, 1919, pp. 1086 and 1191. (Supercharging of Liberty engines.)

**Inv. 1926–418.**

37. 45 H.P. J.A.P. AERO ENGINE, 1908. Presented by Messrs. J. A. Prestwich & Co., Ltd.

This engine was designed and manufactured by Messrs. J. A. Prestwich & Co. Ltd., in 1908, and is interesting as showing an early application of mechanically operated overhead valves.

The cast-iron cylinders are provided with perforated cooling ribs over the upper portion of the cylinder barrel only, a series of exhaust relief ports being drilled in the skirts to assist the clearance of exhaust gases. The valve seatings are detachable from the cylinder heads, the valves being operated by push rods and rockers from an exposed camshaft mounted above the crankcase.

Ignition is by a Bosch D.R.8 type magneto running at twice engine speed. The crankcase is of aluminium divided into four compartments with separate lubrication, the oil being fed to the right-hand cylinder skirts to ensure even lubrication by splash.

The carburetter is a J.A.P. multi-jet automatic type. The crankshaft runs in five white metal bearings, a ball thrust race at the rear end taking the airscrew pull. The big ends have ball bearings.

The principal data are :—Bore, 85 mm. ; stroke, 95 mm. ; capacity, 4,400 c.c. ; weight, 180 lb. ; h.p. at 1,300 r.p.m., 37·43, and at 1,600 r.p.m., 46·84 ; weight per h.p., 3·83 lb.

The manufacturers constructed a Blériot type monoplane during 1909 (first flown April 1910) to which this design of engine was fitted, and two of these engines, one air-cooled and one water-cooled, were the only British exhibits at the first Aero Salon, in Paris, Dec. 24, 1908.

See Jane, *All the World's Aircraft*, 1910–11, p. 414, and (monoplane), p. 57 ; also *Flight*, 1909, pp. 35 and 47. Inv. 1927–32.

38. 9 H.P. J.A.P. ENGINE. Lent by Messrs. A. V. Roe & Co., Ltd. (Shown mounted in the Roe Triplane of 1909.)

This is an air-cooled standard motor-cycle engine, not intended for aircraft use, and it is mentioned here solely on account of a similar engine having been used in flight by Sir A. V. Roe in his first triplane in July 1909. The engine was the smallest power unit which had lifted a man and machine from the ground until the advent of the "Wren" monoplane with A.B.C. engine in 1923. Inv. 1925–443.

39. 50 H.P. N.E.C. ENGINE, 1910. Made by the New Engine Company. Presented by Col. Alec Ogilvie, C.B.E.

This is a two-stroke, blower-fed engine and is actually the first supercharged engine used for aircraft propulsion. The valveless type of this engine, in which, in place of the usual valves of the poppet type, ports or holes are cut in the cylinder walls, was invented by Mr. J. Day in 1891. The engine was designed by Mr. G. F. Mort as an aeroplane engine. It was fitted to Col. Alec Ogilvie's Wright biplane, and was continuously in use from 1911 to 1914.

The example is of the four-cylinder Vee-type, with cylinders cast in pairs and has electrolytically deposited copper water jackets. The cylinders are 3·69 in. (93·5 mm.) bore by 4·5 in. (114 mm.) stroke, and have exhaust and inlet ports cut on opposite sides of the cylinder walls. The exhaust port is cut higher up the cylinder than the inlet port and, consequently, is uncovered first. To drive out the exhaust gas and force in the fresh charge, a Roots blower, divided into three parts, is employed. The two end portions of the blower deal exclusively with pure air, the latter being conducted to the inlet ports through passages cast in the crankcase. The centre portion admits a mixture of air and petrol vapour. Between the central portion of the blower and each pair of cylinders is fitted a rotary valve, of cylindrical shape, running on ball bearings. The function of this valve is to admit the mixture at the right time, and the admission of the charge is delayed until a considerable volume of air has been forced into the cylinder. There is, therefore, between the exhaust gas and the fresh charge, a cushion of pure air. Both the blower and each of the valves have independent enclosed shafts whereby they are driven from the crankshaft.

Lubrication is provided for by a gear-wheel pump that drives oil under pressure to all the bearings, the oil passing through a filter on its return to the pump. The oil consumption is stated to be about 1·5 pints per hour.

The engine is capable of developing 50 b.h.p. at 1,250 r.p.m. The weight complete

is 150 lb. and with water, radiator, and oil sufficient for a flight of five hours, about 220 lb.

Separate examples of parts of N.E.C. engines are shown adjacent.

Inv. 1922–283, 284, 285, and 448.

40. 60 H.P. E.N.V. ENGINE, 1910. Presented by O. C. Morison, Esq.

This is an eight-cylinder, Vee-type, water-cooled engine, manufactured in 1910, by the E.N.V. Motor Syndicate Ltd., London, and fitted to Pischoff, Voisin, Short, and other early type aeroplanes.

The cylinders are arranged at an angle of 90 deg., and are attached to an aluminium crankcase cast in one piece to ensure rigidity. They are of cast-iron, machined inside and out, and have electrically deposited copper water jackets. The crankshaft is supported on six ball bearings with a double thrust at one end to take the pull or push of the airscrew when fitted direct to the shaft. The side-by-side valves are operated by a single camshaft machined out of the solid and hollowed for lubrication purposes. The camshaft is movable in a longitudinal direction and fitted with cams which vary the lift of the valves. One Zenith carburetter supplies the explosive mixture to the cylinders, while ignition is effected by an high-tension magneto with separate distributor. Lubrication is pressure-fed by a force-pump which is actuated by an eccentric on the crankshaft.

The principal data are :—Bore, 105 mm. (4·13 in.) ; stroke, 110 mm. (4·33 in.) ; weight, 310 lb. ; b.h.p., 60 at 1,120 r.p.m. Inv. 1923–384.

41. 60 H.P. WOLSELEY ENGINE, 1910. Lent by the Imperial War Museum.

This is an eight-cylinder, Vee-type, water-cooled engine, and was fitted in 1912 to the first B.E. aeroplane constructed at the Royal Aircraft Factory.

Two rows of four cylinders, cast in pairs, are arranged at 90 deg. to each other, and copper water jackets are screwed to the cylinder castings. Opposite pairs of cylinders are staggered in relation to each other, so as to allow opposite connecting rods to work on the same crankpin. The side-by-side valves are operated by a central camshaft, lifting shoes being interposed between the cams and the tappets.

The explosive mixture is supplied to the cylinders by means of a carburetter, situated in the centre between the two rows of cylinders, and ignition is effected by an H.T. magneto running at crankshaft speed, a separate distributor being fitted and driven from the camshaft. Thermo-syphon cooling and forced-feed lubrication are employed.

The bore is 3·75 in., and the stroke 5 in. Inv. 1923–822.

42. 90 H.P. R.A.F. ENGINE, 1915.

This is an air-cooled eight-cylinder, Vee-type engine and is similar in design to a Renault. It has several improvements, however, the chief of these being the mounting of the crankshaft and camshaft on ball and roller bearings.

Each cylinder and head is cast integrally with air cooling fins, and is secured to the crankcase by two long studs passing up to the cylinder head. The pistons are of cast-iron with three cast-iron rings.

The crankcase is a split aluminium casting. As in the Renault, the upper portion carries the crankshaft, camshaft, and cylinders, while the lower part forms the oil base. A light flywheel mounted on the rear end of the crankshaft, inside the crankcase, serves to distribute oil to the bearings. This flywheel dips into an oil sump and throws off the oil into a passage cast in the flywheel housing, whence it runs into an oil duct alongside the crankcase. Two branch pipes convey it to two of the main bearing caps, whence it flows outwards on either side to oiling rings or oil throwers fixed on to the crank webs. From these the oil is centrifugally forced through the crankpins to the big end bearings. Splash lubrication only is provided for the main roller bearings and cylinders.

The engine is fitted with a cowl so that air entering at the front can only escape round and between the fins on the cylinders. The mixture from the two throttle chambers of a double Claudel-Hobson R.A.F. type carburetter passes up through cored passages in the flywheel cover, and thence through copper induction pipes to the cylinders. Ignition is effected by two magnetos placed on a bracket on the flywheel cover.

The principal data of the engine are :—Normal b.h.p., 93 ; weight, 450 lb. ; bore, 100 mm. (3·93 in.) ; stroke, 140 mm. (5·51 in.) ; normal speed, 1,600 r.p.m. ; petrol consumption, 8·5 gall. per hr. ; oil consumption, 0·5 gall. per hr. ; order of firing, 1, 5,

3, 7, 4, 8, 2, 6. Inlet valve opens 1·5 mm. after t.d.c., and closes 16 mm. after b.d.c.; exhaust valve opens 22 mm. before b.d.c., and closes 1 mm. after t.d.c. Ignition occurs 12 mm. before t.d.c. Inv. 1920–39.

43. SECTIONED 90 H.P. R.A.F ENGINE, 1915. Lent by the Imperial War Museum.

This example is similar in all details to the previous exhibit, but it is sectioned to show its interior parts, and was used for instructional purposes. Inv. 1923–821.

44. 160 H.P. R.A.F. 4A. TYPE ENGINE, 1916.

The general arrangement of this engine, which was built in large numbers, and used successfully in the early part of the war (1914–18), is identical with that of the smaller type.

It is a twelve-cylinder, Vee-type, air-cooled engine, the two sets of cylinders being arranged at an angle of 60 deg. Two B. and B. type carburetters are fitted, while ignition is effected by two six-cylinder B.T.H. magnetos attached to brackets on the airscrew end of the engine.

The principal data are :—Normal b.h.p., 160; weight, 630 lb.; normal speed, 1,800 r.p.m.; order of firing, 1, 7, 4, 10, 2, 8, 6, 12, 3, 9, 5, 11; reduction gear ratio, 2 : 1. Inv. 1920–38.

45. 160 H.P. SUNBEAM "NUBIAN II." ENGINE, 1916.

The "Nubian" is an earlier type of the "Cossack" aero engine, but has eight cylinders only, the two blocks being set at 90 deg.

Details of construction and design are almost identical with those of the "Cossack" engine.

The principal data are :—B.h.p., 164; normal speed, 2,100 r.p.m.; reduction gear ratio, 1·625 : 1; speed of airscrew shaft, 1,290 r.p.m. Inv. 1920–36.

46. 350 H.P. SUNBEAM "COSSACK" ENGINE, 1916.

The "Cossack" is a twelve-cylinder engine and has four valves per cylinder. It was designed for use in airships.

It has cast-iron cylinders arranged in two rows of six each, set in "V" formation at an angle of 60 deg., cast in blocks of three. Each cylinder is provided with two inlet and two exhaust valves of chrome steel, operated by one overhead camshaft to each set of valves, driven by a train of gears from the crankshaft. The pistons are of aluminium. Lubrication is on the dry sump principle, by gear wheel pumps, three being fitted. Carburation is effected by four Claudel-Hobson (C.Z.S.42) carburetters, the petrol feed being by pressure or gravity. Ignition is by means of four B.T.H. (P.M.6) magnetos furnishing independent sparks for two sparking plugs fitted to each cylinder. The engine is water cooled with circulation by centrifugal pump. A governor is fitted which automatically cuts off the ignition when the engine reaches a speed of 2,500 r.p.m., or when the oil pressure falls below 20 lb. per sq. in.

The principal data are :—Weight, 1,200 lb.; b.h.p., 350 h.p.; normal speed, 2,000 r.p.m.; reduction gear ratio, 2 : 1; bore, 110 mm. (4·33 in.); stroke, 160 mm. (6·3 in.); petrol consumption, 24 gall. per hr.; oil consumption, 1·75 gall. per hr.; order of firing, 1, 1A, 5, 5A, 3, 3A, 6, 6A, 2, 2A, 4, 4A; inlet valve opens 3 mm. before t.d.c. and closes 20 mm. after b.d.c.; exhaust valve opens 18 mm. before b.d.c. and closes 5 mm. after t.d.c.; ignition occurs 17 mm. before t.d.c. Inv. 1920–37.

47. 300 H.P. SUNBEAM "MANITOU" ENGINE, 1918. Lent by the Imperial War Museum.

This engine is a twelve-cylinder, water-cooled, Vee-type.

The cylinder blocks are cast in aluminium, with very large water circulation spaces, and are fitted with steel liners and bronze valve seats. Two inlet and two exhaust valves are fitted in the head of each cylinder and are operated by overhead camshafts. A reduction gear and thrust bearing are mounted on an extension of the crankcase, while special bearing caps are provided to take up the side load under working conditions.

Two gravity-fed Claudel-Hobson H.C.7 carburetters are fitted. Ignition is effected by two B.T.H. A.V.12 magnetos. Three oil pumps circulate oil for the lubrication of the engine.

The principal data are :—B.h.p., 300, at 2,000 r.p.m.; bore, 110 mm. (4·33 in.); stroke, 135 mm. (5·3 in.); reduction gear ratio, 1·57 : 1; weight per h.p., 2·8 lb. Inv. 1923–734.

48. 250 H.P. ROLLS-ROYCE "FALCON" ENGINE, 1915. Lent by the Imperial War Museum.

The "Falcon" was the second design introduced by Messrs. Rolls-Royce, Ltd., and was one of the most successful engines of the middle war period (1915–17) until superseded by higher powers. Large numbers were fitted in Bristol Fighter biplanes and Martinsyde scouts. It is a twelve-cylinder Vee-type engine, water-cooled, the cylinders being separate castings with welded steel water jackets. Overhead cam-shafts are fitted, operating single inlet and exhaust valves. The aluminium crankcase is in two halves, with dry sump and scavenging pump and forced feed lubrication. An epicyclic reduction of 56–95 ratio is fitted to drive the airscrew shaft.

The principal data are :—Bore, 4 in. ; stroke, 5·75 in. ; normal b.h.p., 280 at 2,250 r.p.m., the airscrew speed then being 1,327 r.p.m. ; maximum permissible engine speed, 2,500 r.p.m. ; fuel consumption, 18·5 gall. per hr. ; oil consumption, 0·75 gall. per hr. ; weight, dry, 630 lb. without reduction gear, 686 lb. with gear ; weight per h.p., 2·45 lb.

See Jane, *All the World's Aircraft*, 1919, p. 130b. Inv. 1923–733.

49. 360 H.P. ROLLS-ROYCE "EAGLE VIII" ENGINE, 1917. Presented by Messrs. Rolls Royce, Ltd.

The engine here exhibited is one of the engines of the Vickers-Vimy Rolls-Royce aeroplane, which made the first direct trans-Atlantic flight on June 14–15, 1919.

It is a twelve-cylinder, Vee-type, water-cooled, left-hand tractor engine, in which the two sets of cylinders are arranged at an angle of 60 deg., similar in general design to the "Falcon."

The cylinders are of special wrought steel construction, and the pistons, which are specially designed for high compression, are each fitted with four piston rings. There is an oil scraper at the bottom of each piston. The pistons of opposite cylinders are operated by master and articulated connecting rods respectively and work on a six-throw crankshaft. Explosive mixture is supplied to the cylinders by four Rolls-Royce Claudel-Hobson carburetters, fitted with a high altitude control, and ignition is effected by four six-cylinder Watford magnetos, each cylinder being provided with two ignition plugs.

The airscrew shaft is driven through an epicyclic reduction gear of 0·6 to 1.

The principal data of the engine are :—Bore, 4·5 in. ; stroke, 6·5 in. ; normal b.h.p., 360 ; weight, 900 lb. ; normal speed, 1,800 r.p.m. ; normal airscrew speed, 1,080 r.p.m. Ignition occurs at 13–15 deg. before t.d.c. when fully retarded, and 33–35 deg. before t.d.c. when fully advanced.

The order of firing of this engine is 1A, 6B, 4A, 3B, 2A, 5B, 6A, 1B, 3A, 4B, 5A, 2B.

Inlet valve opens 10 deg. after t.d.c. and closes 54 deg. after b.d.c. ; exhaust valve opens 58 deg. before b.d.c. and closes 10 deg. after t.d.c. Inv. 1919–476.

50. 650 H.P. ROLLS-ROYCE "CONDOR" ENGINE (SERIES III), 1922. (SECTIONED AND OPERATING.) Lent by Messrs. Rolls-Royce, Ltd.

This engine is of the Vee type, consisting of two banks of six cylinders placed 60 deg. apart.

The cylinders are separately mounted, are of built-up construction, with heads integral with the barrels, and have welded sheet water jackets. There are two inlet and two exhaust valves per cylinder, the valve seatings being machined in the heads. The overhead camshafts are mounted in steel tubes and brackets bolted to the cylinder heads ; the middle cam operates the two inlet valves, and each of the outer cams operates one exhaust valve.

The pistons are of aluminium alloy, with two gas rings and a scraper ring above the gudgeon-pin, and a scraper ring at the base of the skirt. The connecting rods consist of one plain and one forked end to each crankpin, of H-section, machined all over. The plain rod works on the centre portion of a divided white metal lined sleeve bolted to the forked rod. The small ends are fitted with floating bronze bushes. All bearings are positively oiled under pressure, through suitable leads and the hollow crankshaft, to the gudgeon-pin bearings, splash oiling being used for the cylinders. The camshafts are driven by inclined tubular shafts and bevel gearing from the rear end of the crankcase. The six-throw crankshaft, with all journals and crankpins bored out, is carried in seven plain bearings, with white metal liners.

The straight tooth reduction gear has a ratio of just under 2·1 to 1, and has a special hub (not shown), bolted to the flange provided, for the use of metal airscrews.

The Rolls-Royce, Claudel-Hobson type twin carburetter is mounted low to

facilitate gravity feed, but, where this is impossible, a petrol pump may be spigot-jointed to the drive. A special altitude control controls the flow of petrol to the jets. The induction pipes are jacketed at the intake end. Starting up is by means of gas distribution to all cylinders, and a hand-starting magneto. A machine gun interrupter gear is fitted. Two 12-point B.T.H. magnetos are employed.

The principal data are :—Bore, 5·5 in. ; stroke, 7·5 in. ; normal b.h.p., 650 ; normal speed, 1,900 r.p.m. ; airscrew shaft, 907 r.p.m. ; consumption, fuel, 45 gall. per hr. ; oil, 1·9 gall. per hr. ; weight of engine, all on, not including radiator, airscrew, water, oil, and fuel, 1,336 lb. ; weight per b.h.p., 2·055 lb. at normal speed and power, or 1·96 lb. at test b.h.p. at normal speed, or 1·88 lb. at test b.h.p. at maximum permissible speed of 2,100 r.p.m. Inv. 1924–602.

51. 450 H.P. NAPIER "LION" ENGINE (SERIES IB), 1918. Presented by the Air Ministry.

This is a twelve-cylinder, water-cooled, double-Vee or "broad arrow" type of engine, developing 450 h.p., and designed by Messrs. D. Napier & Son, Ltd.

Three blocks of four cylinders each are mounted on a single crankcase, with an angle of 60 deg. between the rows. Each block of cylinders is built up of four steel liners secured to an aluminium head casting, and sheet-steel water jackets are welded on. Each head casting carries two camshafts which lie directly above the line of valves which they operate and contains the inlet and exhaust ports. Two inlet and two exhaust valves are fitted in the head of each cylinder and are directly operated by the camshafts. The crankshaft has four throws, while the connecting rod assembly consists of a master rod and two side rods carried on lugs integral with the big end of the master rod.

The front end of the crankcase encloses a reduction gear for the airscrew shaft together with the shaft and bearings, while the other end supports an aluminium casing which houses the oil and water pumps, the bevel gears and the magneto drive.

The explosive mixture is supplied to the cylinders by two carburetters, a single and a duplex type, and ignition is effected by two B.T.H. A.V.12 magnetos. A patent self-starting device is fitted to this engine. It pumps the explosive mixture into the cylinders, and fires it by means of a hand-starting magneto.

The principal data are :—B.h.p., 450 at 2,000 r.p.m. ; bore, 5·5 in. ; stroke, 5·125 in. ; compression ratio, 5·8 : 1 ; reduction gear ratio, 1·52 : 1 ; weight per h.p. 1·89 lb. Inv. 1923–400.

52. 450 H.P. NAPIER "LION" ENGINE (SERIES V), 1924. (SECTIONED AND OPERATING.) Lent by Messrs. D. Napier & Son, Ltd.

This is a development of the earlier "Lion" engine. It has twelve cylinders, and is of the "broad arrow" type, having three banks of four cylinders, each mounted above the crankshaft centre line, the outer banks being placed 60 deg. either side of the central vertical bank.

Each cylinder is a separate unit, machined, integral with its combustion head from a steel forging, the water jackets being welded on. The cylinders are secured to the crankcase by bolted flanges, and, at their heads, by an aluminium alloy casting, forming the combined valve port and camshaft housing.

Flat-topped pistons of aluminium alloy are fitted, each with two piston rings and one scraper ring above the gudgeon-pin and one scraper ring below. The gudgeon-pins are hollow, parallel outwardly, and held by a taper set screw through one piston boss.

The connecting rods of the vertical banks are the "master" rods, the outer ones being articulated to the master big end ; all are of channel section. The crankshaft is massive, hollow through all journals and crankpins, and runs on five roller bearings of the cageless "packed" type, the three larger middle ones being threaded over the shaft and mounted on split packing bushes.

The airscrew shaft, driven at reduced speed from the crankshaft by spur gearing, is carried in two roller bearings and is provided with a double ball thrust bearing.

The oil and water pumps, magneto drives, and camshaft gearing are mounted in an aluminium casing at the rear end of the crankcase. Two twelve-cylinder B.T.H.-A.V. type magnetos are used, giving dual ignition to each cylinder.

A patent self-starting device is fitted consisting of a means for pumping explosive mixture into the cylinders and for firing it by a hand-driven magneto.

Lubrication is by the dry sump system, two draining pumps and one pressure pump, all of the spur-wheel type, being fitted. The oil is distributed through the hollow crankshaft to the big end and gudgeon-pin bearings, with splash lubrication to the cylinders ; a separate pressure lead supplies the camshafts, the surplus oil passing over the reduction gearing on its way back to the sump.

Gas is supplied by one single and one duplex carburetter forming virtually three carburetters. The bore of the cylinders is 5·5 in.; stroke, 5·125 in.; r.p.m., crankshaft 2,000; airscrew shaft 1,320; b.h.p., 460 at 2,000 r.p.m., with 5·8 : 1 compression ratio, or 435 b.h.p. with 5 : 1 ratio; weight, dry, 900 lb.; weight per b.h.p., 1·95–2·07 lb., according to compression ratio. Inv. 1925–375; 1926–183.

## *FRENCH*

53. 50 H.P. ANTOINETTE ENGINE, 1905–7. Lent by the War Office.

The part which the Antoinette engine played in the development of flight in Europe from 1906 until the advent of the Gnome rotary engine has been fully described in the introductory Technical Survey. The example shown is the typical 50 h.p. eight-cylinder model and was fitted to the first British military airship, "Nulli Secundus," in 1907.

It is of the Vee-type arranged in planes at right angles to one another, four on each side of the crankshaft. The cylinders are machined from steel forgings and are mounted on an aluminium crankcase and held by loose yokes at their flanges. The cylinder heads contain the inlet and exhaust valves; the former are of the spring-loaded automatic type, while the latter are mechanically operated. No carburetter is employed, the petrol being injected directly above the inlet valves by means of a variable stroke pump.

Brass water jackets are shown on the example, but electrolytically deposited copper were usually employed. A feature of this type of motor is the cooling arrangement. Very little water is carried, the water being converted into steam, which is then condensed by a tubular condenser (not shown). Splash lubrication is employed, the oil pump, water pump and variable-throw fuel pump being all driven by belts direct from the crankshaft.

Ignition is by means of an accumulator and trembler coil, in conjunction with a distributer mounted on the crank chamber and driven by the camshaft. The latter is driven by exposed gearing. Inv. 1913–453.

54. 50 H.P. "ANTOINETTE" ENGINE, 1909. Lent by Messrs. the Blackburn Aeroplane and Motor Co., Ltd. (Shown mounted in the Antoinette monoplane.)

This engine is generally similar to the preceding example, but it is of interest as showing the typical method of mounting with the aluminium tube condenser fitted to the sides of the fuselage. The system of steam cooling with subsequent condensation at atmospheric pressure, instead of by water at a temperature below boiling point, thus permitting a higher cylinder temperature, has of late years been advocated and investigated in connection with automobile engines. Inv. 1926–542.

55. 200 H.P. CLERGET ENGINE, 1911. Lent by the Imperial War Museum,

This engine is an eight-cylinder, water-cooled engine with copper water jackets. and was constructed by the Etablissements Malicet et Blin, France. Overhead valves operated by single push rods are fitted in each cylinder. The lower half of the aluminium crankcase is provided with fins for the purpose of cooling the oil in the crank-chamber sump. Two carburetters and two H.T. magnetos are fitted.

The principal data are:—B.h.p., 200 at 1,275 r.p.m.; bore, 140 mm. (5·5 in.); stroke, 160 mm. (6·3 in.); weight, 500 lb.; weight per h.p., 2·5 lb. Inv. 1923–791.

56. 80 H.P. RENAULT ENGINE, 1913.

This engine was designed by Messrs. Renault Frères, Billancourt, Seine, France, and was afterwards produced in large numbers in this country during the war period (1914–18). It is an eight-cylinder Vee-type air-cooled engine, with the two sets of cylinders arranged at an angle of 90 deg.

The cylinders and cylinder heads are separate, both being of cast iron, with air-cooling fins cast on each, and they are secured to the crankcase by means of a clamp and long studs from the crankcase.

The inlet valves work in valve cages, which also form the elbow for the inlet pipe, operated directly by a tappet from the camshaft. The exhaust valves are in the cylinder heads and are operated by overhead rocking levers and push rods. The steel pistons are fitted with three cast-iron piston rings. Opposite cylinders being in line, the connecting rods are articulated on one side and direct on the other. The four-throw crankshaft is carried in five bearings, the centre and two intermediate ones being gun-metal lined with white metal, and the outer ones ball bearings. The crankcase

is of aluminium, divided horizontally along the centre line of the crankshaft, the upper portion containing the bearings, camshaft, and gears, and the lower portion forming an oil base and carrying the oil pump, strainer, and oil pressure release valve.

A Claudel-Hobson carburetter of the R.A.F. type, and an eight-cylinder B.T.H. A.8 type magneto are fitted.

The camshaft and airscrew shaft are driven from the crankshaft through a reduction gear of 2 to 1.

The principal data of the engine are :—Bore, 105 mm. (4·13 in.) ; stroke, 130 mm. (5·12 in.) ; normal speed, 1,800 r.p.m. ; airscrew shaft speed, 900 r.p.m. ; nominal h.p., 80 ; approximate weight, without fan or cowl, 480 lb. ; capacity of oil base, 3 gall. ; petrol consumption, 75 pt. per hr. or 0·72 pt. per b.h.p. hr. ; oil consumption, 7·5 pt. per hr. ; indicated h.p., 105 ; inlet valve opens at 5 deg. or 0·5 mm. after t.d.c., closes at 53 deg. or 20·5 mm. after b.d.c. ; exhaust valve opens at 59 deg. or 25·5 mm. before b.d.c., closes at 18 deg. or 4·5 mm. after t.d.c. ; ignition occurs 34 deg. or 13·5 mm. before t.d.c. Inv. 1920–46.

## *ITALIAN*

57. 700 H.P. F.I.A.T. ENGINE (TYPE A.14), 1923. Presented by the Italian Government.

This is a twelve-cylinder aero-engine of Italian design manufactured by the Societa Anonyma F.I.A.T. of Turin.

The specification is as follows :—Power, maximum at 1,700 r.p.m., 750 h.p. ; average, 1,650 r.p.m., 685 h.p. ; guaranteed, 1,650 r.p.m., 625 h.p. ; normal speed, 1,650 r.p.m. ; maximum speed, 1,700 r.p.m. ; No. of cylinders, 12 ; cylinder bore, 170 mm. (6·7 in.) ; stroke, 210 mm. (8·27 in.) ; ratio of compression, 4·5 ; total weight, dry, 730 kg. (1,606 lb.) ; approximate total weight with water and radiator, 845 kg. (1,860 lb.) ; petrol consumption per h.p. hr., average, 0·220 kg. ; oil consumption per h.p. hr., average, 0·022 kg. ; ignition system, 4 magnetos, 12 cyl. ; No. of valves per cylinder, 4 ; No. of carburetters, 4. Inv. 1927–811.

## *SPANISH*

58. 200 H.P. HISPANO-SUIZA ENGINE, 1917.

This very successful engine was designed by La Sociedad Hispano-Suiza, Barcelona, Spain, and was also built during the war period (1914–18) by a large number of firms in France, England, and America. The engine here exhibited is of French production, being made by Messrs. Peugeot. It is the first engine in which screwed steel liners were used in conjunction with monobloc cast-aluminium jackets and heads, as already described in the introductory Technical Survey.

It is an eight-cylinder, Vee-type, water-cooled engine, with the cylinder blocks set at an angle of 90 deg. The cylinders are arranged in groups of four, the cylinders of each group forming a block which is of built-up construction.

The water jackets and valve ports are cast of aluminium, and the individual heat treated steel liners of the cylinders are threaded into the aluminium castings. The pistons are ribbed aluminium castings, and the connecting rods tubular. The crankcase is in two halves, divided horizontally on the centre line of the crankshaft, the lower portion forming an oil base. Lubrication is by a positive pressure system, the oil being forced through a filter and by way of steel tubes cast in the crankcase, to the main bearings, and through the crankshaft to the crankpins. A Zenith duplex carburetter is fitted, and two eight-cylinder magnetos effect dual ignition.

The principal data are :—Normal b.h.p., 220 ; weight, 503 lb. ; normal speed, 2,000 r.p.m. ; compression ratio, 4·7 to 1 ; bore, 120 mm. (4·72 in.) ; stroke, 130 mm. (5·12 in.) ; reduction gear, 2–1·17 ; petrol consumption, 15·6 gall. per hr. ; oil consumption, 1·6 gall. per hr. ; order of firing, 1, 5, 2, 6, 4, 8, 3, 7. Inv. 1920–41.

59. 200 H.P. HISPANO-SUIZA "CANON PUTEAUX" ENGINE, 1917.

This exhibit exemplifies the only known attempt to arrange a gun to fire through the airscrew shaft, the object being to enable a larger projectile than can be fired from the usual Vickers-Maxim or Lewis guns to be discharged forward from a tractor aeroplane without interfering with the airscrew.

A special aeroplane, W.B.5, was designed by Messrs. William Beardmore & Co. (see Jane, *All the World's Aircraft*, 1919) to accommodate this engine and gun, but the combination was not adopted during the war (1914–18), the Armistice intervening before development.

For detail particulars of the engine see the adjacent exhibit, where a similar type is shown.

The gun is mounted in the Vee formed by the two banks of cylinders, the recoil being taken by a spring housed in the cylinder mounted over the barrel, the stresses being transmitted by the cylinder to the airscrew reduction gear casing and the forward part of the engine, to avoid straining the crankcase.

The return stroke of the recoil mechanism is regulated by an oil dashpot,the piston being fitted with a valve free to open on the recoil stroke to permit the transfer of oil from one side of the piston to the other. The valve is closed on the return stroke, when the oil is forced to travel through the hollow piston rod and out through small holes into the spring chamber, this restriction governing the speed of the return. A conical plug which enters into the hollow piston rod serves to throttle the flow of oil progressively during the latter part of the return stroke, so that the gun and breech mechanism come up into place without shock. An oil and air reservoir is arranged at the forward end to compensate for the unbalanced volume when the piston rod is withdrawn. The bore of the gun, which is unrifled, is 37 mm. (1·457 in.).

The breech block is of the falling type, actuated by two sets of trigger gear on the right-hand side, one catch unlocking the breech, the other positively throwing it down. The ejection of the spent cartridge case is accomplished by a fork ejector, kicked by the falling breech block, and the spent case, during ejection, re-cocks the firing hammer.

The provision for ammunition storage, and the method of loading, closing the breech, and dealing with the disposal of the spent cartridge are not shown.

Inv. 1924–384.

## OPPOSED CYLINDER ENGINES

### *BRITISH*

60. 28–30 H.P. A.B.C. ENGINE, 1917.

This engine was designed and manufactured by Messrs. Walton Motors, Ltd., early in 1917, and it was one of the first examples of two-cylinder opposed aeroplane engines produced in this country.

The cylinders are of steel with aluminium pistons and cast-iron piston rings.

The two-throw crankshaft has the big ends set at 180 deg.

The principal data are :—Bore, 110 mm. (4·3 in.) ; stroke, 120 mm. (4·72 in.) ; h.p., 45 at 2,500 r.p.m. Inv. 1924–383.

61. 3 H.P. A.B.C. ENGINE, 1923. Lent by the English Electric Co., Ltd. (Shown mounted in the "Wren" Monoplane.)

This is an example of the use of specially tuned motor-cycle engines in light aeroplanes—as described in the introductory Technical Survey—which resulted from the movement towards the use of very light and small powered aeroplanes, in 1922. As specially tuned, this engine developed about 5 b.h.p. Inv. 1924–603.

### *FRENCH*

62. 50–60 H.P. DARRACQ ENGINE, 1909. Presented by Messrs. the Bristol Aeroplane Co., Ltd.

This is a horizontal, four-cylinder, opposed type engine, made by Messrs. Darracq et Cie., and is interesting as being one of the earliest designs to be fitted with mechanically operated inlet and exhaust valves, situated in the cylinder head in what in vertical engines is known as the overhead position.

The cylinders, of steel, with welded steel water jackets, are mounted in pairs on either side of the aluminium crankcase. The camshaft is mounted in an enclosing portion of the crankcase above the crankshaft, and is driven by spur gearing at the rear end, an idler wheel being introduced to drive the Bosch type D.4 magneto. All bearings are plain gun metal with forced feed lubrication. An eccentric and big end for driving the oil pump (not shown) are fitted at the rear end of the camshaft ; the front end of this shaft drives the water circulating pump.

The horizontal opposed design was previously represented only by the Dutheil-Chalmers engines.

The two-cylinder Darracq engine, of same bore and stroke, was used during 1909 by M. Santos-Dumont, in his "Demoiselle" monoplanes. The example shown is stated by the donors to have been fitted in the first aeroplane made by them, about the middle of 1910.

The bore is 130 mm. (5·12 in.) and stroke 120 mm. (4·72 in.). The actual power developed was about 45 h.p.

See *Flight*, 1909, pp. 577, 591, 603, and 623, and Jane, *All the World's Aircraft*, 1910–11, p. 420. Inv. 1926–852.

63. 28 H.P. NIEUPORT ENGINE. Lent by the Imperial War Museum.

This engine of French design has two cylinders horizontally opposed. It is air-cooled. It was fitted to a single-seater Nieuport aeroplane in 1912, but became obsolete on account of its small power.

Two overhead valves are fitted in each cylinder, operated by push rods from the crankcase, and forced lubrication is adopted.

The principal data are :—B.h.p., 28 at 1,200 r.p.m. ; bore, 135 mm. (5·3 in.); stroke, 150 mm. (5·9 in.) ; weight, 154 lb. ; weight per h.p., 5·5 lb. Inv. 1923–739.

## RADIAL TYPE ENGINES

### *BRITISH*

64. 320 H.P. A.B.C. "DRAGONFLY" ENGINE. Sectioned in the Museum Workshops.

This is a nine-cylinder, air-cooled engine of British design remarkable for its very low weight (1·88 lb.) per horse-power developed. It is the largest of a series of radial engines manufactured by Messrs. Walton Motors, Ltd., for use by the R.A.F. during the late war (1914–18).

This engine, which is known as the "Dragonfly," has cylinders machined from steel forgings and provided with radiating fins over the greater portion of their length, the outer surface being coated with deposited copper to assist radiation. The heads of the cylinders are machined integral with the barrels and are bored to receive the overhead valves. One large inlet and two smaller exhaust valves are fitted, operated by push rods and rocker arms from the cam gear situated in the front portion of the crankcase. The pistons are of the aluminium alloy "slipper" type, with two piston rings above the gudgeon-pin.

The master connecting rod, of channel steel, is integral with the big end, the remaining rods being articulated to the big end. Lubrication is by means of two rotary pumps, one feeding through the hollow crankshaft to the crankpin, the other feeding the cams and gears in the nose. Two H.C.8 carburetters and two A.K.9 magnetos are fitted.

The principal data are :—Bore, 5·5 in. ; stroke, 6·5 in. ; b.h.p., 320 at 1,650 r.p.m. ; fuel consumption, 0·56 pt. per b.h.p. hr. ; oil consumption, 7 pt. per hr. or 0·021 pt. per b.h.p. hr. ; rotation, anti-clockwise facing airscrew ; weight of engine, 600 lb. or 1·88 lb. per h.p. Inv. 1924–382.

65. 400 H.P. BRISTOL "JUPITER" ENGINE (SERIES IV), 1921. (SECTIONED AND OPERATING.) Lent by the Bristol Aeroplane Co., Ltd.

This is a nine-cylinder, radial, air-cooled engine of a type which has been used with considerable success.

The cylinder barrels, with radiating fins, are machined from steel forgings, and fitted with aluminium alloy heads, the joint being maintained by studs and set screws. The heads embody the valve ports and carry the valve gear, spherical seating floating guides being used for the inlet valves. The valves are operated by push rods from cam rings driven at one-eighth engine speed by an epicyclic gear in the nose. The rockers are mounted on the fulcrum pin carried in the rocker bracket which is anchored to the cylinder head at its rear end and tied to the crankcase at its front end. As the engine warms up and the cylinder expands radially the rocker bracket is held by the tie rod at the front end, about which it pivots, giving the variations of movement required between the rocker fulcrum and the cylinder to obtain the desired compensating effect. The cylinders are each fastened to the crankcase by 8 bolts.

The pistons are of aluminium alloy, fitted with 2 gas rings and a scraper ring in the skirt. The gudgeon-pin floats in both piston and connecting rod. The master rod with its hardened steel liner is of one piece, and all the rods are of channel section. The crankshaft is in two pieces, with floating bush bearing for the master rod. The power transmitting portion is solid, and the accessory driving portion is rigidly secured by a clamping bolt and integral key. The auxiliary units are grouped at the rear of the engine.

A Triplex carburetter is fitted consisting of 3 carburetters in 1 unit. The 3 starts of the induction spiral, form, with the spiral chamber, 3 separate channels, each isolated

from the others and fed by 1 carburetter feeding 3 evenly spaced cylinders. The heated induction elbow assists vaporization. Two 9-point magnetos are fitted, giving dual ignition to all cylinders.

The principal data are :—Bore, 5·75 in. ; stroke, 7·5 in. ; power at 1,550 r.p.m. (normal speed) 400 b.h.p., at 1,575 r.p.m. (max. speed) 435 b.h.p. Consumption of fuel at normal speed and power 0·594 pt. per h.p. hr. ; oil 0·049 pt. per h.p. hr. ; weight, 730 lb. ; weight per h.p. at max. speed, 1·68 lb. Inv. 1925–739.

66. 400 H.P. ARMSTRONG-SIDDELEY "JAGUAR" ENGINE. (SECTIONED AND OPERATING.) Lent by Messrs. Armstrong-Siddeley Motors, Ltd.

This is a fourteen-cylinder, radial, air-cooled engine, designed to meet an Air Ministry "ideal" specification.

The cylinders are steel barrels, machined from solid ingots with radiating fins provided over the full length of the exposed portion, and are fitted with aluminium alloy heads screw shrunk on to the tops of the barrels and locked in position by a nut forming an extra radiating fin. The combustion space is roughly spherical, with valve ports and guides cast in, bronze valve seats being expanded in. The rocker arms operate direct on to the ends of the valve stems and swing on ball bearings. Interchangeable inlet and exhaust valves are fitted, operated by push rods from cam rings running at one-sixth engine speed by an epicyclic gear in the nose. The cylinders are fastened to the crankcase by a double-coned locking ring.

The pistons are of aluminium alloy fitted with two gas rings and a scraper ring above the gudgeon-pin and a further scraper ring below. The large diameter gudgeon-pins float in the piston, and also run in floating bushes in the small ends of the steel connecting rods. These are machined all over, the master rod being of channel section, and the remainder of tubular section. The big end proper is connected by two pins to the master rod. The articulated rods have floating pins and bushes, both in their big ends and in the master big end side flanges. The two-throw crankshaft is in one piece, carried on three roller bearings, with a double-acting ball thrust race at the airscrew end.

One pressure and one scavenging oil pump, both of the gear type, are fitted, the dry sump system of lubrication being adopted. The oil under pressure is distributed twice through the crankshaft, with leads to the connecting rod big and small ends and controlled splash oiling for the cylinder walls.

A dual type of carburetter is fitted with a choice of air intakes to regulate warmth ; the mixture passes by way of an exhaust heated portion of the inlet pipe to a centrifugal fan on the tail of the crankshaft, which ensures even distribution to all cylinders ; the hot oil from the scavenging pump also passes behind the fan chamber and helps to warm the mixture.

Two 14-point magnetos are mounted behind the engine, giving dual ignition to all cylinders.

The principal data are :—Bore, 5 in. ; stroke, 5·5 in. ; power at 1,700 r.p.m., normal speed, 385 b.h.p., at 1,870 r.p.m. max. speed, 420 b.h.p. ; consumption of fuel, at normal speed and power, 0·525–0·55 pt. per h.p. hr. ; oil consumption, at normal speed and power, 0·03 pt. per h.p. hr. ; weight, 775 lb. ; weight per h.p. at max. power, 1·845 lb. Inv. 1924–570.

## *FRENCH*

67. 25 H.P. ANZANI ENGINE, 1908. Presented by the late Major J. D. B. Fulton.

The example shown is an air-cooled, three-cylinder, semi-radial petrol engine of the type used by M. L. Blériot in 1909 in his cross-Channel flight. It is of simple design and is one of the smallest engines yet fitted to an aeroplane.

The cylinders, each with its head and valve chamber, are separate castings and are ribbed circumferentially in order to provide a large cooling surface. They are attached to an aluminium crank chamber which is cast in halves, the portions being held together by long through bolts. The angle between adjacent cylinders is 60 deg. and the order of ignition is 1, 3, 2, taking No. 2 cylinder as the vertical central one. Atmospheric induction valves, situated above the exhaust valves, are employed ; the latter are operated by separate camshafts. Auxiliary exhaust ports are provided in the cylinder walls which are uncovered by the pistons at the ends of their strokes. The connecting rods are coupled to the common crankpin, two of the big ends being forked to allow of this. A balanced flywheel is provided to compensate for the out-of-balance effect of the fan-type setting of the cylinders.

The carburetter is of the float feed type. Additional air supply is provided for by

a number of holes drilled round the base of an annulus in the mixing chamber. The holes are covered normally by balls held in position by a cover plate, and as the suction increases the balls rise from their seats.

The principal data are :—Bore, 105 mm. (4·13 in.) ; stroke, 130 mm. (5·1 in.) ; weight, with accessories, 65 kilo. (143 lb.) ; the h.p. is 25 at 1,600 r.p.m.

See *Flight*, Oct. 30, 1909. Inv. 1914–183.

68. 35 H.P. ANZANI ENGINE, 1909. Lent by the Imperial War Museum.

This is similar in detail design to the preceding example, but the cylinders are regularly disposed round the crankcase at 120 deg. apart. They are of cast iron. Each cylinder is equipped with one inlet and one exhaust valve, the latter being operated by push rods from a cam gear in the crankcase, whilst the inlet valves are of the spring controlled automatic type. The explosive mixture is supplied by a Zenith carburetter. The ignition is effected by H.T. magneto. Forced feed lubrication is adopted.

The principal data of this engine are :—B.h.p., 30 at 1,300 r.p.m. ; bore, 105 mm. (4·13 in.) ; stroke, 120 mm. (4·72 in.) ; weight per h.p., 3·5 lb. Inv. 1923–743.

69. 100 H.P. ANZANI ENGINE, 1910.

This radial, air-cooled engine of double-star formation is a development of the preceding three-cylinder type, and was made by the British Anzani Engine Co., Ltd.

The engine consists of two groups each of five cylinders, each group forming a five-branch star in a plane perpendicular to the engine axis. The axes of the cylinders of the two groups are arranged alternately so that the whole engine from the front has the appearance of a regular star with ten points. The cylinders, which are of cast iron, have ribs of special section, and are secured by means of small columns passing through lugs cast solid with the cylinder.

The cast-iron pistons are machined internally and externally to reduce weight, and are each fitted with two patent conically seated piston rings. The nickel steel connecting rods of H-section drive on to a hollow nickel chrome steel two-throw crankshaft running in two ball-bearing journals. Two nickel steel valves are fitted in each cylinder head, the exhaust valve being operated by a rocking lever while the inlet valve is automatic.

The aluminium crankcase is made in two halves, bolted together with long through bolts. Forced lubrication is fitted, and oil is pumped under pressure to the crankshaft bearings and thence to the big ends of the connecting rods, through holes drilled in the webs and pins. The oil thrown out by centrifugal force fills the crankcase with a mist of oil which thoroughly lubriates the pistons, gudgeon-pins and all moving parts. The oil pump is enclosed in a watertight compartment cast solid with the valve gear cover.

The explosive mixture is supplied to the cylinders through radial pipes lodged in a groove formed in the ribs, drawing gas from a chamber, at the lower end of which is a Zenith carburetter. Dual ignition is effected by two high tension magnetos of the Watford type.

The data of the engine are :—Weight, 363 lb. ; power, 100 h.p. ; bore, 105 mm. (4·13 in.) ; stroke, 145 mm. (5·7 in.) ; angle between cylinders, 36 deg. ; normal speed, 1,250 r.p.m. ; petrol consumption, 7 gall. per hr. ; oil consumption, 2 gall. per hr. The cylinders fire successively in the following order in a direction opposite to that in which the shaft rotates, 1, 8, 5, 2, 9, 6, 3, 10, 7, 4. Exhaust valve opens 45 mm. before b.d.c. and closes 3 mm. after t.d.c. Ignition occurs 6–10 mm. before t.d.c.

Inv. 1920–45.

70. 110–130 H.P. SALMSON ENGINE (CANTON-UNNÉ SYSTEM), 1912.

The " Salmson " aero-engines, invented jointly by MM. Canton and Unné, are manufactured on the Continent by the Société Anonyme des Moteurs " Salmson," of Billancourt, Seine.

The engine exhibited is a nine-cylinder water-cooled engine of the radial type. The cylinders, which are placed symmetrically around the crankshaft, are of nickel steel machined from solid forgings, the finished thickness of the working barrels being 2 mm. The flat-topped combustion chambers carry bosses into which the casings of the mechanically operated inlet and exhaust valves are screwed. Water jackets of spun copper are brazed to the cylinders and corrugated to permit the working barrels to expand.

The flat-topped cast-iron pistons are each fitted with three cast-iron rings, and are secured by hollow tungsten steel gudgeon-pins to H-section steel connecting rods, all of which operate on one crankpin by means of a steel cage or connecting rod carrier.

The aluminium crankcase is in halves, between which the cylinders are securely clamped and from which the cambox is detachable.

The lubrication is forced, a double pump being fitted below the cambox; one pump draws oil from the crankcase sump and delivers it to an external reservoir, where it is cooled, and from where it is drawn by the other pump through a fine wire gauze filtering screen to a sight feed box, whence it is delivered by means of the crankshaft and cambox to the big ends, and by exudation to the pistons and gudgeon-pins.

Two specially designed Zenith carburetters placed on the horizontal axis of the engine, deliver the explosive mixture through hot-water jacket branches into an annular mixing chamber, and thence by the induction pipes to the several cylinders, in which ignition is effected by a Siemens' magneto. The engine drives through a reduction gear of 1·8–1, thereby allowing an airscrew of larger diameter to be employed.

The data of the engine are :—Weight, 360 lb. without radiator ; normal b.h.p., 130 h.p. ; bore, 4·73 in. ; stroke, 5·52 in. ; normal speed, 1,250 r.p.m. ; angle between cylinders, 40 deg. ; petrol consumption, 9·5 gall. per hr. ; oil consumption, 0·5 gall. per hr. ; order of firing, 1, 3, 5, 7, 9, 2, 4, 6, 8. Inlet valve opens 1–2 mm. before t.d.c. and closes 18–20 mm. after b.d.c. Exhaust valve opens 18–20 mm. before b.d.c. and closes 1–2 mm. before t.d.c. Ignition occurs 12–13 mm. before t.d.c.

Inv. 1920–42.

## ROTARY ENGINES

### *BRITISH*

71. TRAVERS EXPERIMENTAL ROTARY ENGINE, 1908–9. Lent by H. G. Travers, Esq.

This is a small experimental three-cylinder rotary engine, designed by Mr. J. L. Travers, in 1908–9. It is interesting as showing the system of single-valve design later exemplified by the Gnome Mono-Soupape type engines.

The cylinders are of steel, and each carries side flanges and a quadrant flange, so that, when all bolted together, these flanges form each a third part of the " crankcase," the back plate thus formed being reinforced by a clamping ring. The crankshaft is stationary, and serves as an entry for the oil and petrol pipes, the fuel being pumped by a gear-driven pump from the gear wheel rotating with the crankcase, a rotary distributor, attached to the front of the cylinder skirts, receiving the pumped petrol, and distributing it through small pipes to injector nozzles, situated in the compression spaces.

The single valve in the cylinder head serves both as exhaust and inlet valve, and is operated by a bell-crank lever and push rod to the overhead rocker, the motion being given by a scroll cam, mounted on the crankshaft, and serving, by the arrangement of its guide flutes, as a 2–1 reduction gear for the 4-cycle operation. No provision is made for taking off the power developed.

The pistons are of cast iron, and domed, their diameter being 4 in., and stroke 3 in. The gear-driven pump is shown detached, adjacent.

Inv. 1926–730 and 1001.

72. 150 H.P. B.R.1 ENGINE.

This engine (the Bentley Rotary), which was designed by Capt. W. O. Bentley, M.B.E., and produced by Messrs. Humber, Ltd., Coventry, was used extensively towards the end of the war (1914–18).

The cylinders, which are of aluminium shrunk on to cast-iron liners, are arranged radially round a fixed crankshaft. Each cylinder is provided at its lower end with five shallow stiffening ribs, above which is a series of deep radiating fins. A feature of the design is the method of cooling employed, which consists in the use of a highly conducting distributive jacket combined with radiating fins. This feature was patented by Mr. R. Ayton in 1898. The combustion heads, which are of machined steel, are made in one piece with the induction pockets, into which steel inlet valve guides are pressed, while the exhaust valve cages into which cast-iron valve guides are pressed are also in one piece with the heads. The cylinders and combustion heads are attached to the crankcase by four long bolts located at the corners of each cylinder, the cooling fins being cut away to allow clearance. The pistons are of aluminium alloy, have slightly concave heads, and are provided with five very shallow cast-iron rings set in grooves near the top of the piston. Holes are drilled in the piston skirt to allow the oil from inside the piston to escape on to the cylinder walls. The connecting rods are of tubular section steel.

Inlet and exhaust valves are both operated by overhead rocker arms and tappets

each of which is connected to a push rod by a ball joint. The cam gear comprises two internally toothed rings known as " gear rings," within which are the corresponding externally toothed gears.

Forced lubrication is employed, and oil from the pump is led to an orifice in the crankshaft, through which it is conducted by a copper pipe to a duct in the base of the rear web of the hollow crankpin. A by-pass at the foot of the rear crankpin supplies oil to the thrust box. The bulk of the oil forced along the pipe inside the crankshaft travels up the duct in the rear web to the crankpin, where the stream diverges again into supplies for the connecting rod assembly, the pistons and the cylinders on the one hand, and for the cam gear box on the other hand.

The Bloc-tube carburetter is screwed on the extreme rear end of the hollow crankshaft, through which the explosive mixture passes to the orifice at the foot of the rear web of the crank, whence it passes into the main crankcase. It is then sucked through a ring of holes into the gas chamber, which rotates with the thrust box and through the induction pipes, into the cylinders. Ignition is provided by two M.L. magnetos of the revolving armature type, giving two sparks per revolution.

The principal data of the engine are :—Normal b.h.p., 154 ; weight, dry, 408 lb. ; normal r.p.m., 1,250 ; bore, 120 mm. ; stroke, 170 mm. ; petrol consumption, 13 gall. per hr. ; oil consumption, 1·5 gall. per hr. Inv. 1920–44.

73. 200 H.P. B.R.2 ENGINE. Lent by Messrs. Gwynnes, Ltd.

The sectioned engine shown is a later type of the Bentley rotary engine (B.R.1) designed by Capt. W. O. Bentley, M.B.E.

The stationary crankshaft is built up of three pieces, the main crank, the short crank, and an extension or cam-gear shaft. There are four main ball bearings on the crankshaft, two of which support the thrust box and two the cam-gear box. The master connecting rod is supported on the crank by two large ball bearings. The crankcase proper is bolted to the thrust box which is in rear, and to the cam-gear box which is in front. The nine cylinder barrels are of cast aluminium shrunk on to steel liners. The lower end of the barrel is formed with a spigot which fits loosely into the crankcase, thus allowing for expansion. The method of cooling employed consists in the use of a highly conducting distributive jacket combined with radiating fins. This feature was patented by Mr. R. Ayton in 1898. The cylinder heads are of steel and are attached to the cylinders and crankcase by means of four long bolts. The pistons are of aluminium alloy and have slightly concave heads. Five very shallow cast-iron rings are set in grooves near the top of each. The nine connecting rods are of tubular section steel and, with the exception of the master rod, are bushed with phosphor bronze at both ends. The valve mechanism closely resembles that in the earlier engine, but volute springs are substituted for the coiled type in order to allow a greater lift. The cam mechanism is similar to that in the earlier engine, the driving gear being of the Clerget type.

Ignition is provided by two M.L. magnetos of the revolving armature type. Lubrication is effected by means of a Le Rhône type oil pump. A Bloc-tube carburetter (not shown) is usually fitted. It consists of a short extension, screwed to the rear of the long crank, and contains the jet and throttle slide.

The principal data are :—Normal b.h.p., 238 ; normal r.p.m., 1,300 ; bore, 140 mm. ; stroke, 180 mm. ; fuel consumption, 21 gall. per hr. ; oil consumption, 2·25 gall. per hr. Inv. 1921–715.

## *FRENCH*

74. 50 H.P. GNOME ROTARY ENGINE, 1908. Lent by Sir F. K. McClean.

The " Gnome " motor is of French design, and it materially assisted towards solving the problem of obtaining a reliable aeroplane engine which is capable of developing sufficient horse-power without excessive weight. In this type of engine the crankshaft is stationary, and the cylinders and crank-chamber revolve round it.

The example shown has seven nickel-steel cylinders 4·3 in. diameter by 4·7 in. stroke, machined with their air-cooling ribs out of the solid. The crank-chamber is also of steel, and the seven cylinders are held in position by split-steel rings, which are sprung into grooves turned in the cylinders so that the cylinders cannot be withdrawn without removing the rings. Taper-pins of special section, which pass through the rim of the crank-chamber, securely lock these rings in position. Piston rings of L-section brass are employed, similar in shape to the cup-leather of an hydraulic piston. The end plate, on which the airscrew is fixed when used, as in the example, as a tractor screw, carries on the inside the cams and gear wheels which operate the exhaust valve rods. Ball bearings are used to support the engine as a whole upon the stationary crankshaft, and a thrust-block is provided at the rear end of the engine.

The connecting rods all operate on a single crankpin. The big end of one of them, embracing the crank and mounted on ball-bearings, is formed into a cage, the outer rings of which carry the plain bearings for the remaining six connecting-rods.

The carburetter, which is stationary, is of the single-jet type, and feeds the engine through the hollow crankshaft, petrol flowing thence into the crank-chamber, from which each cylinder obtains its mixture by means of an automatic inlet valve of the mushroom type situated in the piston-head. The valve seating also acts as a means of connection between the piston and the connecting rod.

The exhaust valves are situated in the cylinder heads, and are operated by twin balanced rocking levers actuated by long push rods connected with the cams contained in the end plate of the crank-chamber. The cams consist of seven flat steel collars with a common boss keyed on to a spindle, and are operated by an epicyclic train of wheels, the fixed wheel being on the end of the stationary crankshaft. Both the inlet and the exhaust valves are balanced against centrifugal force by means of counterweights.

An odd number of cylinders is necessary in order that the firing of the mixture in each cylinder may be carried out at equal angular intervals, and thus give an even torque, *e.g.* if the mixture in cylinder No. 1 were fired first, the order of firing would be 1, 3, 5, 7, 2, 4, 6, and repeat.

Ignition is effected by a Bosch high-tension magneto, mounted on a stationary bracket in an inverted position, and driven by gearing. The distribution of the electric current to the sparking-plugs is effected by a revolving commutator plate and a stationary brush. Firing of the charge occurs just before the cylinder concerned reaches its highest position, the piston then being at the top of its stroke. Bare brass wires are employed as connections between the sparking-plugs and the commutator.

Lubrication is provided for by a reciprocating-pump driven in a similar manner to the magneto, and mounted on the same plate. Castor oil only is used, and is injected into the hollow crankshaft through sight-feed fittings, and from thence to each cylinder.

When running at the normal speed of 1,200 r.p.m. the engine develops 50 b.h.p. The weight per h.p. is approximately 3·44 lb. Inv. 1913–446.

75. 50 H.P. GNOME ENGINE, 1908. (SECTIONED AND OPERATING.) Lent by the Imperial War Museum.

The Gnome rotary engine was originally conceived in 1907 by M. Laurent Seguin, and materially assisted towards solving the problem of obtaining a reliable aero-engine for a minimum of weight. In this engine the crankshaft is stationary, and the cylinders and crank-chamber revolve round it.

The sectioned example shown has seven cylinders, machined out of solid nickel-chrome-steel ingots, and held in position by split-steel rings, which are sprung into grooves turned in the cylinders. Taper-pins of special section, which pass through the rim of the crankcase, securely lock these rings in position.

The connecting rods all operate on a single crankpin. The big end of one of them embraces the crankpin and is mounted on ball-bearings ; it is formed into a cage, the outer rings of which carry the plain bearings for the remaining six connecting rods.

The carburetter, which is stationary, is of the single-jet type, and feeds the engine through the hollow crankshaft, petrol passing thence into the crank-chamber, from which each cylinder obtains its mixture by means of an automatic inlet valve of the mushroom type situated in the piston head. Ignition is effected by a stationary gear-driven Bosch magneto, and lubrication is provided for by a reciprocating pump, mounted on the magneto plate.

The principal data are :—B.h.p., 50 at 1,200 r.p.m. ; bore, 110 mm. (4·33 in.) ; stroke, 120 mm. (4·72 in.) ; weight per h.p., 3·44 lb. approximately.

Inv. 1923–825.

76. 80 H.P. MONOSOUPAPE GNOME ENGINE. (SECTIONED.) Lent by the Imperial War Museum.

This engine is a development of the Gnome engine and was introduced in 1913. As its name implies, it is provided with only one valve in each cylinder—a mechanically operated exhaust valve.

The sectioned example shown has seven cylinders of nickel-chrome-steel machined from the solid, while the pistons are of the ordinary cast-iron type. The inner ends of the cylinders project into the crankcase, and contain a belt of ports, over-run by the piston when near the bottom of its stroke and thereby functioning as an inlet valve.

The petrol is pressure-fed from the tank to a petrol jet situated in the crankcase,

and air is admitted into the cylinders through the exhaust valve. When the piston overruns the belt of ports the rich mixture is admitted into the cylinder, compressed by the upward stroke of the piston and then fired. The speed of the engine is controlled by varying the duration of the opening of the exhaust valves.

The principal data are :—B.h.p., 80 at 1,200 r.p.m. ; bore, 110 mm. ; stroke, 150 mm. Inv. 1923–824.

77. 100 H.P. MONOSOUPAPE GNOME ENGINE.

This engine is a development of the ordinary Gnome engine and, as its name implies, is provided with only one valve in each cylinder : a mechanically operated exhaust valve situated in the cylinder head.

It is a nine-cylinder, rotary, air-cooled engine, the cylinders being arranged radially and symmetrically round the fixed crankshaft. The cylinders, which are of nickel chrome steel, are machined from the solid, while the pistons are of cast iron, each having a thick concave crown connected solidly by webs to the gudgeon-pin bosses. A hollow steel gudgeon-pin is fixed in the piston boss by a single steel set-screw with a conical prolongation.

The crankcase, which is in two portions, comprises two steel castings secured together by nine bolts ; the cylinders are located by keys, and held by a recess turned in the bottom of each. The inner ends of the cylinders project into the crankcase and contain a belt of ports, overrun by the piston when near the bottom of its stroke, and thereby functioning as an inlet valve. The massive steel cone-seated exhaust valve which is situated in the cylinder head is actuated by a rocker and push rod, the centrifugal effect of which balances that of the valve. An improved form of lubrication is fitted in this type of engine by means of which the gudgeon bearings are supplied with oil passing outwards from the big end cage along the hollow webs of the connecting rods, while the oil exuding from the gudgeon bearing is led by two ducts to the cylinder walls. The cam sleeve, cams, and camshaft gears are also positively lubricated by oil supplied from the crankshaft through a series of ducts. The petrol is pressure-fed from the tank to a copper pipe running inside the crankshaft, thence through the centre of the large crank web, hollow crankpin and small crank web, to the petrol jet, which is situated in the crankcase where the mixture is so rich as to be non-explosive. Air is admitted into the cylinder through the exhaust valve, while the rich mixture enters by way of the belt of ports at the inner end of the cylinder. A Bosch magneto of the D.A.L. type is fitted.

The principal data of the engine are :—Normal b.h.p., 105 ; weight, 297 lb. ; speed, 1,200 r.p.m. ; bore, 110 mm. ; stroke, 150 mm. ; petrol consumption, 10 gall. per hr. ; oil consumption, 2 gall. per hr. ; order of firing, 1, 3, 5, 7, 9, 2, 4, 6, 8 (the cylinders are numbered 1 to 9 consecutively, in a clockwise direction when facing the propeller). Cylinder ports open 20 deg. before b.d.c. and close 20 deg. after b.d.c. ; exhaust valve opens 85 deg. after t.d.c. and closes 60 deg. before b.d.c. (the exhaust valve being open continuously during 395 deg. of rotation). Ignition occurs 18 deg. before t.d.c. Inv. 1920–49.

78. 100 H.P. MONOSOUPAPE GNOME ENGINE. (SECTIONED AND OPERATING.) Lent by the Imperial War Museum.

This engine is similar to the 80 h.p. Monosoupape Gnome, but has nine cylinders and contains some minor improvements.

An improved form of lubrication has been adopted by means of which the gudgeon bearings are supplied with oil passing outwards from the big end cage along the hollow webs of the connecting rods, while the oil exuding from the gudgeon bearing is led by two ducts to the cylinder walls.

The principal data of the engine are :—B.h.p., 100 at 1,200 r.p.m. ; bore, 110 mm. (4·33 in.) ; stroke, 150 mm. (5·9 in.) ; petrol consumption, 10 gall. per hr. ; oil consumption, 2 gall. per hr. ; weight per h.p., 2·6 lb. ; compression ratio, 4·95–1. Inv. 1923–826.

79. 80 H.P. LE RHÔNE ENGINE. Presented by Messrs. W. H. Allen, Son & Co., Ltd.

This engine was invented by M. Verdi in 1912 and was originally produced in Paris by the Société des Moteurs Gnome et Rhône, in 1913.

During the war (1914–18) it was produced in quantities for H.M. Government by the donors and was fitted in, amongst other aeroplanes, D.H.5, Sopwith " Pup," Sopwith " Camel," Avro, and Bristol Scout.

It was the first rotary engine to embody mechanically operated inlet and exhaust valves. Four different sizes are made, with power outputs of from 50 to 160 h.p. The

example shown is of the nine-cylinder, 80 nominal h.p. type. The valves are located in the cylinder head, both being operated by one push rod and rocker from the cam rings, of which there are two, each of which functions for both inlet and exhaust valves. Radial pipes from the crankcase to the inlet valve casing convey the mixture to the cylinders. The exhaust valves are placed on the leading, or airscrew side, of the engine, in order to obtain the fullest possible cooling effect. Thin cast-iron liners are shrunk into the steel cylinders to reduce piston friction.

The principal data are :—90 h.p. at 1,200–1,300 r.p.m. ; bore, 4·5 in. (114 mm.) ; stroke, 6 in. (152 mm.) ; weight, approx. 2·85 lb. per h.p. ; engine built of steel practically throughout and consists of 1,156 pieces. Inv. 1919–345.

## 80. 80 H.P. CLERGET ENGINE (TYPE 7Z).

The Clerget engine was designed and built by Clerget, Blin et Cie., Levallois-Perret, and built under licence in this country by Messrs. Gwynnes, Ltd., Hammersmith.

This engine is of the rotary type, having seven steel cylinders provided with fins for air cooling. The inlet and exhaust valves are situated in the cylinder head and are mechanically operated independently by push rods and rockers actuated by two eccentrics which are keyed to the extension shaft.

Each piston is provided with three cast-iron cut rings, in addition to double obturator rings of special silver alloy, and drives an independent hollow steel connecting rod. One of these, the main rod, is continuous with the banjo at the crank end, and holds all the pistons in their correct relative positions. The hollow steel crankshaft, which is coned and keyed for attachment to the central support, is always fixed with the crankpin on the top centre, and is held in position by a locked sleeve nut. An oil pump ensures efficient lubrication and a M.L. type magneto is fitted. Mixture is supplied to the cylinders through radial external induction pipes from a simple form of carburetter which is screwed on the end of the crankshaft, the air being regulated by a butterfly valve controlled by a lever, while the petrol jet is not adjustable. The airscrew is attached directly to the crankcase.

The principal data of the engine are :—Weight, 234 lb. ; speed, 1,200 r.p.m. ; normal b.h.p., 80 ; bore, 120 mm. ; stroke, 150 mm. ; number of cylinders, 7 ; order of firing, 1, 3, 5, 7, 2, 4, 6 ; inlet valve opens at t.d.c., closes 56 deg. after b.d.c. ; exhaust valve opens 68 deg. before b.d.c., closes at t.d.c. ; ignition occurs 22 deg. before t.d.c. ; fuel consumption, 7 gall. per hr. ; oil consumption, 1·5 gall. per hr.

Inv. 1920–40.

## 81. 130 H.P. CLERGET ENGINE.

This nine-cylinder rotary air-cooled engine is a development of the adjacent smaller engine.

The main principles of this engine are identical with those of the adjacent one, from which it differs only in a few characteristic improvements.

The cylinders and connecting rods are of steel, while the pistons of this engine are of aluminium, and the steel crankshaft is somewhat heavier than is usual in rotary engines. A Bloc-tube carburetter is fitted, while ignition is effected by two A.D.S. magnetos.

The principal data are :—Normal b.h.p., 130 ; weight, 381 lb. ; bore, 120 mm. (4·72 in.) ; stroke, 160 mm. (6·30 in.) ; compression ratio, 4 to 1 ; normal speed, 1,250 r.p.m. ; petrol consumption, 10·65 gall. per hr. ; oil consumption, 1·73 gall. per hr. ; order of firing, 1, 3, 5, 7, 9, 2, 4, 6, 8.

See *Flight*, Feb. 13, 1919. Inv. 1920–47.

## 82. 150 H.P. CLERGET ENGINE (TYPE 9 B.F.) Lent by Messrs. Gwynnes, Ltd., London.

This is an example of the most recent type of Clerget engine manufactured in this country. It resembles in general design the earlier models, but has several minor improvements and greater power owing to increased cylinder capacity.

The engine has spiral exhaust valve springs instead of the " grasshopper " type fitted to the earlier models. An air pump is provided for the purpose of maintaining the petrol pressure. This pump has no suction valve, the air being admitted through the holes in the barrel when the plunger is near the inward end of its stroke. The delivery valve is of the plate type and of large size. The pump supplies the air required to displace the petrol used and delivers an ample margin to allow for any small leakage from the delivery pipe or petrol tank. An adjustable relief valve is provided to deal with the excess of air. The oil pump is of the Clerget type as fitted to the earlier models.

A gun interrupter gear is mounted on the thrust box casing behind the cylinders. It enables a fixed machine gun to be fired through the airscrew.

The principal data are :—Number of cylinders, 9 ; bore, 120 mm. ; stroke, 172 mm. ; speed, 1,250 r.p.m. ; weight, including oil pump, air pump, and two magnetos, 400 lb. ; the inlet valve opens 4 deg. before t.d.c. and closes 56 deg. after b.d.c. ; the exhaust valve opens 68 deg. before b.d.c. and closes 4 deg. after t.d.c. ; magneto timing, 22 deg. early. Inv. 1921–714.

### *GERMAN*

83. 110 H.P. OBERURSEL ENGINE. Presented by the Air Ministry.

This German rotary engine, with the exception of a few minor details, is almost an exact copy of the French 110 h.p. Le Rhône engine.

The pistons of this engine are of aluminium, and are provided with only four rings and two oil grooves, one above and one below the gudgeon-pin, while the crown of each piston has 12 radial ribs, which are absent in the French design. The method of locking the gudgeon-pin is also different from the French, while the valve stems are machined with tapered recesses into which are fitted split valve ring collars. The crankcase is a steel casting and the nose piece is separate from the front cover.

The principal data of the engine are :—B.h.p., 120 ; normal speed, 1,200 r.p.m. ; bore, 112 mm. ; stroke, 170 mm. ; petrol consumption, 10·1 gall. per hr. ; oil consumption, 1·3 gall. per hr. ; inlet valve opens 13 deg. after t.d.c. and closes 21 deg. after b.d.c. ; exhaust valve opens 61 deg. before b.d.c. and closes 28 deg. before t.d.c. Inv. 1920–357.

## ENGINE DETAILS

84. RADIATOR OF D.H.10 AEROPLANE. Presented by the Aircraft Manufacturing Co., Ltd.

This is a radiator of the ordinary honeycomb type, used extensively on motor cars, but specially manufactured for aircraft use.

Two of these radiators are fitted in front of the two power units on the D.H.10 aeroplane. The cooling efficiency of the radiator can be regulated by means of the metal shutter (described in the adjacent exhibit).

The radiator is fitted, at the top, with a screw-capped filler. The outlet pipe from the engine, which returns the water, circulated by a pump, to the radiator, has its entry just below this filler. At the centre, the radiator is cut away to allow for the engine shaft, which carries a tractor airscrew immediately in front of the cooling surface. The inlet pipe to the engine is fitted at the base. The radiator is provided with lugs which engage with the engine bearers, and it is supported in this manner. Inv. 1920–598.

85. RADIATOR SHUTTER. Presented by the Aircraft Manufacturing Co., Ltd.

This shutter was designed by Capt. L. C. Bygrave for shielding radiators when exposed to very low temperatures. The effect of a low temperature on an uncovered radiator is to cause over-cooling and consequent loss of engine efficiency.

The shutter consists of a series of metal strips pivoted laterally and arranged in the manner of the slats in a Venetian blind. The maximum opening is when the strips are horizontal, and in this position the radiator has the full benefit of the cooling draught induced by its passage through the air and by any head wind which may be blowing. If over-cooling takes place the shutter may be partially or completely closed by means of the control in the pilot's cockpit.

This device is often found useful in the initial stages of a flight when it is desired to heat up the engine quickly. Inv. 1920–598.

86. POLAR INDUCTOR MAGNETO. Lent by the British Thomson-Houston Co., Ltd.

This is a sectioned example of the A.V.8 S-type of polar inductor magneto. It is suitable for an eight-cylinder aircraft engine. Examples of the materials used in construction are shown adjacent.

This type of magneto has a stationary armature and a rotor consisting of four iron masses mounted upon a " straight-through " shaft of non-magnetic steel. The current which produces the spark is generated in the stationary armature and reaches its maximum four times during each revolution of the rotor, or polar inductor ; accordingly four sparks are produced per revolution. The masses of iron which

form the polar inductor are alternately North and South poles, so that in sweeping past the ends or poles of the laminated circuit they cause, on each occasion, a reversal in the flux.

The beginning of the primary winding is connected to the armature core and the end to the secondary winding and to the contact breaker. A cam operates the rocker arm, separating the contacts four times per revolution of the shaft. When the contacts are closed the primary winding is short-circuited, and, as the inductor rotates, the current induced in the primary winding builds up until the cam separates the contacts at the instant when this current is at a maximum. The instantaneous collapse and reversal of the flux at the moment of "break" produces the high voltage in the secondary winding which causes the spark.

The distributor consists of a rotating metal brush which conveys the high tension current to the various segments; the sparks are thus distributed to the various plugs on the engine. A condenser is fitted above the armature and a safety spark gap is provided between a point on the metal brush box and a stud on the half-speed gear wheel. The inductor shaft is driven at engine speed. Inv. 1919–277.

87. CANTON-UNNÉ MAGNETO. Presented by the Air Council.

This magneto has an armature inductor which is revolved at half crankshaft speed, and runs between magnetic pole pieces connected to a permanent magnet. This system was later almost universally abandoned in favour of the fixed armature shield types shown adjacent. Inv. 1919–434.

88. BOSCH H.L.6 TYPE MAGNETO. Presented by the Lords Commissioners of the Admiralty.

This is a sectioned example of the H.L.6 type of polar inductor magneto. It is designed to fire a six-cylinder engine.

A description of a technically similar type will be found adjacent, but, in this case, instead of four masses of iron, two only, in the form of a rotating shield, are used to form the rotor which revolves about, and cuts the magnetic field of the stationary armature. It is driven at one and a half times engine speed, thus giving three sparks per revolution of the crankshaft. This example has been removed from the Zeppelin-Maybach Airship engine (see No. 20). Inv. 1919–426.

89. BOSCH Z.H.6 TYPE MAGNETO. Presented by the Air Council.

This example, which has been removed from a Benz aeroplane engine, is similar to the H.L.6 type shown adjacent, but is designed to be weather-proof for use with semi-exposed mountings, common in German aeroplanes. Inv. 1920–356.

90. LODGE AERO SPARKING PLUG, TYPE K.R.3. Presented by the Air Council.

This well-known sparking plug has been used considerably on aircraft engines. The type shown is suitable for a stationary engine. It is mechanically strong, and has an insulation capable of withstanding the very high temperature to which a sparking plug on a stationary engine is subjected. Radiating fins are supplied to assist in the cooling of the centre rod and the body of the plug.

The Lodge sparking plug, type K.R.3, is fitted with a central rod and single electrode insulated from the body by mica. A high-tension terminal with a spring washer is provided at the end of the central rod. Radiating fins form a part of the securing member, which is screwed down to the mica insulation. These fins materially assist in dissipating the heat passing from the electrode up the central rod, and enable the former to be kept at a temperature which will not cause pre-ignition. The body of the plug is also cut away in order to provide a large surface for cooling purposes. The spark gap is annular, between the central electrode and a circular plate forming part of the body of the plug. Inv. 1919–432.

91. K.L.G. SPARKING PLUGS. Lent by the Robinhood Engineering Company, Ltd.

This exhibit shows various types of plugs manufactured by the Robinhood Engineering Co., Ltd., for use on aero engines.

No. 1. Type F.7.—This type was used extensively during the late war (1914–18) on low-compression engines, such as the Hispano-Suiza, R.A.F., and Renault.

The electrodes are of white metal, with a single spark gap. The centre rod is insulated from the body of the plug by mica, placed vertically as well as horizontally,

the securing nut being of brass and screwed against an asbestos washer to maintain gas tightness.

No. 2. Type F.12.—This model was produced during 1918. It is designed to withstand great heat and high compression, and is heavier in construction than F.7, the central electrode having been increased, whilst the gas capacity has been decreased. It is used with Rolls-Royce, Bristol, and Liberty engines, and, in a slightly modified form, for the Napier "Lion" and Siddeley "Puma" engines. It was used on the first trans-Atlantic and Australian flights.

No. 3. Type 144.—This plug is an experimental type, and has not been produced in quantities. Its performance is comparable with that of F.12, though its durability is considered to be less.

No. 4. Type C.B.—This plug was produced prior to 1914 for use on Sunbeam racing motor cars. It has been found suitable for engines such as the Sunbeam "Maori," with very high compression ratio, and it can withstand the highest temperatures. This type was used on the R.34 airship during her voyages across the Atlantic. The design is different to the foregoing, having a central electrode of copper, and the mica insulation mounted in the body of the plug and not on the centre rod, the upper part of the rod being insulated with mica placed vertically as well as the ordinary insulation. The rod is tapered from the bottom so that the explosion pressure tends to tighten the joint. Radiating fins are provided to assist the cooling of the rod and electrode.

No. 5. Type 180.—This is a more recent design intended to withstand even higher temperatures than type C.B. It was developed for modern racing cars, and racing motor cycles; it is, therefore, suitable for aircraft engines fitted with superchargers.

No. 6. Miniature.—This design was developed for very small cylinders in high-speed engines, the size facilitating the design of the combustion chamber due to the reduction of area required for the plug entry.

No. 7. Wireless Shield.—This screen has been developed in conjunction with the Marconi Wireless Telegraph Company in order to minimise the radiation from the ignition system, which is particularly troublesome on short-wave reception. The screen can be used with any type of plug, and provides a continuous metal conductor from the body of the plug to the metal braiding which surrounds the high-tension wire.

Inv. 1925–103 to 109.

92. RENAULT SPARKING PLUG. **Presented by the Air Council.**

This sparking plug is designed for a stationary air-cooled aero-engine. It is made with large surface radiating fins to assist in the cooling and so maintain a temperature which will not cause pre-ignition. The plug has a 6-point spark gap.

The central rod terminates in a star-shaped electrode of six points. It is insulated from the body of the plug by a mica cylinder, and the whole is held in position by a screw collar, which, with an asbestos washer, forms a gastight joint. This sparking plug is designed to withstand, by means of a large radiating surface, the very high temperature which a stationary air-cooled engine attains. Inv. 1919–433.

93. BOSCH IGNITION SWITCH. **Lent by the Air Council.**

This switch is designed to control the ignition where two magnetos are used to supply current for two plugs in each cylinder.

The accompanying diagram shows the wiring from the switch ("umschalter"). The marking "O" on the casing indicates "off"; "M.1" indicates magneto No. 1 and is the position for using the starting magneto; "M.2" is for magneto No. 2; "2" is for both magnetos. Inv. 1921–508.

94. AEROPLANE TANK. **Lent by the Imperial War Museum.**

This represents a combined petrol and oil tank for a single-seater fighting scout, arranged, since space longitudinally in such machines is limited, to accommodate the stored cartridge belt for a machine gun mounted over the tank, and provided with passages for the spent cartridge cases and the disintegrating belt links respectively to pass down on their way to the Jettison chute out of the fuselage.

The tank is built of copper sheet, the ends being clink seamed and soldered, and stiffened by a flute, rolled into the body sheet close to the seam. The petrol and oil compartments are separated by a double bulkhead, riveted and soldered in position, the space between being ventilated to prevent any possibility of leakage between the two parts. The oil tank has an internal wash plate to damp surging, the passages through the petrol tank performing the same function.

Each tank has a connection for pressure air at the top, with a union beneath to join the pipe lines, and adjacent drain plugs for washing out. Inv. 1923–1347.

## 95. AIRSHIP PETROL TANK.

This tank represents the general system used for fuel storage on rigid airships prior to 1922; it consists of a simple circular tank of 65 gall. capacity, with dished ends, built up and welded together, the material being thin aluminium sheet.

To distribute the stresses the tank is slung vertically in a sheet steel sling with eyes at the two upper ends. These eyes are attached to quick releasing catches, similar to those used for releasing bombs, so that in emergency, to lighten the ship, or in case of fire, the petrol tanks can be selectively jettisoned. On each side, at the top and bottom, simple guides, felt lined to guard against any chance of sparks being struck, guide the released tank in its fall through openings provided in, or adjacent to, the lower corridor, these openings being generally provided with lightly attached covers insufficiently robust to withstand the impact of the falling tank. The petrol connections to the fuel pipe line are also arranged to be broken by the fall.

The general scheme of the arrangement of the tanks will be seen in the sectional drawing accompanying the model of H.M.A. R.34. In this airship, which is typical of early post-war practice, there were normally sixty-one tanks with a total capacity of 3,965 gall. On her Atlantic flight, R.34 carried eighty-seven tanks with a total fuel capacity of 5,455 gall. The pipe lines are so arranged that any tank can be fed to any engine, as desired. Inv. 1921–495.

## 96. PETROL FEED PUMP. Presented by the Aircraft Manufacturing Co., Ltd.

This is a sectioned example of a pump used to supply petrol to the carburetter. It is mounted vertically in the tank and is driven by a small airscrew which is caused to revolve by the slipstream from the propeller. The pump was produced by the Aircraft Manufacturing Co., Ltd., and was fitted in duplicate to several types of de Havilland aeroplanes.

This pump is of the rotary type, the mechanism consisting of a drum fitted with two sliding blades placed opposite each other and kept mutually expanded by means of a small coil spring, the whole being cased excentrically. Petrol enters through a gauze strainer and is caused, by the rotation of the drum, to pass up the vertical outlet pipe, the flow being almost continuous. An automatic valve is fitted to this pipe to ensure an even pressure and to give an outlet to the tank should the delivery be checked at the carburetter. The driving mechanism consists of an airscrew 18 in. in diameter connected by bevel gearing with the vertical shaft which rotates the drum.

The tank in which this pump is mounted is placed in the centre section of the aeroplane so that the driving mechanism receives the full force of the slipstream. Inv. 1920–595.

## 97. ALUMINIUM PETROL COCK. Presented by the Imperial War Museum.

This type of petrol cock is used on large machines, such as the Handley-Page o/400 and V.1500. Inv. 1927–361.

## 98. THREE-WAY PETROL SUPPLY COCK. Presented by W. O. Manning, Esq.

Inv. 1927–63.

## 99. BLOC-TUBE CARBURETTER.

This type of carburetter is screwed to the end of the long crankshaft of the Bentley rotary and Clerget engines. The example shown was fitted to a 80 h.p. Clerget engine. Its body consists of a short extension housing the jet and throttle slide, which constitute the vital parts of the carburetter. The air intake pipes are secured in a lug fitted to the rear end of the body. The jet projects horizontally into the tubular body of the carburetter opposite the throttle slide, in the end of which is mounted a tapered needle. As the slide is moved the needle is plunged into, or withdrawn from, the jet, so varying the effective aperture. The throttle resembles in shape a shallow box set on edge, and is mounted in guides to move across the tubular body; the face farthest from the engine is hinged and tightly pressed against the guiding slide by an internal spring to make a gas-tight joint. Unions for petrol drain pipes are provided below the mixing chamber. A fine adjustment valve (not shown) controlled by a separate lever, is always used in conjunction with this carburetter. Inv. 1920–40.

## 100. ZENITH AERO CARBURETTER. Lent by the Lords Commissioners of the Admiralty.

This is an example of the well-known carburetter manufactured by the Zenith Carburetter Co., Ltd., and used extensively with aero-engines. The chief characteristic is the fitting of an auxiliary or compensating jet in addition to the main jet.

It has also a slow-running device and removable choke tube. The carburetter shown is suitable for a four-cylinder engine.

The main jet is fitted in the centre of the compensating jet, being inserted from beneath when the plug is removed. It is fed directly from the float chamber. The compensating jet is inserted from above, and can be seen in position covering the main jet. The bore of each jet is marked on it in hundredths of a millimeter, so that a very fine adjustment can be effected by discriminate changing.

The slow-running device consists of a small jet situated in a tube, which is part of the carburetter casting, and adjacent to the main intake. It has an air intake above it, through two holes in the casting, which can be plainly seen. At low-engine speeds, when the throttle, which is of the ordinary central-pivoted type, is almost closed, the slow-running device comes into operation and gases are sucked into the main intake from the small jet through a passage above the throttle. In this position the main and compensating jets are practically shut off, and the partial vacuum induced by the engine has its full effect upon the small jet. As the throttle is opened the slow-running device is progressively cut out. The mixture is kept more or less constant at all speeds, by means of the compensating jet, which corrects the irregularities of the main jet; it has a greater influence at low speeds, while the main jet has most effect at high speeds.

Adjustment is effected by changing the choke tube, the main and compensating jets, and regulating the slow-running device.

An advantage of this carburetter is, that when once properly adjusted, it requires no attention, unless the conditions of service are radically altered. Inv. 1919–431.

101. CLAUDEL HOBSON CARBURETTER. Lent by the Air Council.

This type of carburetter was used considerably on aircraft engines during the war (1914–18). The example shown is of a type supplied to the Royal Air Force, and is known as Mark I.A. It has two jets, mixing chambers, throttles, etc., but one common float chamber. The carburetter is suitable for an eight-cylinder (80 h.p.) Vee engine.

The principal feature of this twin carburetter is the automatic mixture control, obtained by means of the specially designed cylindrical throttle which forms a variable choke tube as it is opened. The main jets have holes in their outer casings through which the air for atomizing the petrol passes. Adjustment for strength of mixture is provided by two screws fitted just above each air intake. When these are screwed in, the actual suction on the jet is increased and the mixture is enriched. Provision is made for shutting off all the air for starting purposes. This is effected by the fitting of a central-pivoted throttle in each air intake. A large straining device and sump is arranged at the base of the carburetter, the petrol being fed directly from this to the float chamber. The two throttles are connected in such a manner that an equal opening is obtained. Inv. 1919–430.

102. BROWN AND BARLOW CARBURETTER.

This is a carburetter in which a jet, or fuel delivery orifice, in series with the main jet, is so incorporated that it is adapted to supply fuel when the throttle occupies a position, or positions, intermediate to those which are effective for obtaining fuel from the main jet.

Independent air releases communicate with the spaces above the intermediate and pilot jets. The induction elbow, shown detached, is heated by the exhaust gases from the engine. The carburetter has been removed from a R.A.F.4a aero-engine.

(For further particulars, see Patent Spec. 127022.) Inv. 1920–38.

103. CRANKSHAFT FOR N.E.C. ENGINE. Presented by Chester Mort, Esq.

This six-throw crankshaft is a part of the 60 h.p., six-cylinder aero-engine designed in 1910 by Mr. G. F. Mort and produced by the New Engine Co.

The N.E.C. engine from which this shaft was taken worked on the two-stroke cycle and the shaft ran at an average speed of about 1,200 r.p.m. It was remarkable for the extremely low weight (13·75 lb.) obtained without sacrificing strength.

Inv. 1922–284.

104. SILENCER FOR ENGINE. Presented by the Air Council.

This silencer is designed for a moderately powered aero-engine. It is made of aluminium and is cast in two pieces, which, being bolted together, are easily removable for cleaning purposes.

The exhaust pipe from the engine is connected at the blunt end of the silencer and the gases thus entering impinge against the four inclined baffle-plates which are a part of the casting. The gases are thus divided and induced to follow the streamline form of the silencer till they encounter a series of holes and escape. Inv. 1919–428.

105. ALBION-MURRAY MECHANICAL LUBRICATOR. Presented by the Albion Motor Car Co., Ltd.

This is a sectioned example of the lubricator patented by Mr. T. B. Murray and the makers in 1905. It was designed for use on aeroplane engines, where compactness and lightness are essential. The lubricator delivers oil under pressure to fourteen different points, the delivery to each being capable of independent regulation.

The lubricator consists of an oil container, on the bottom of which are formed two circular discs, each having in its surface 14 holes arranged in a circle, alternate holes leading to the oil container and to one of the delivery pipes. Rotating over the discs, and kept in close contact with them by coiled springs, are two other discs driven by a worm lying between them and engaging with teeth cut in their peripheries. Each disc carries a vertical single-acting pump, the plunger of which is depressed by a series of cams fixed to the top of the container and returned by a helical spring surrounding the plunger. As the disc revolves and the pump comes over a hole connected with the reservoir, the plunger rises under the action of the spring, and oil is sucked into the barrel. As the pump is carried further, it comes over a delivery port and the plunger, which has a roller at its upper end, is forced down by a cam and the charge of oil is expelled. This action takes place seven times per revolution of each disc. The distance through which the plunger rises on the suction stroke can be adjusted by screws attached to the highest flat portions of the cam race, so that the amount of oil drawn in can be regulated. The drive is taken from the engine to the worm shaft by a vertical shaft and bevel gearing. Inv. 1919–234.

106. ENGINE STARTER. Presented by the Air Council.

This is an example of the compressed air starter designed for use on the 220 h.p. Renault aero-engine. Compressed air is supplied from a compressor (not shown), and is fed to the six cylinders through a simple type of rotary valve. A ratchet device makes the starter inoperative when the engine is running. A starting magneto (not shown) is mounted at the top of the casting and is driven at high speed by suitable gearing.

The aluminium casting, which comprises the cylinders, the crankcase, and the mounting for the starting magneto, is bolted to the rear of the engine in such a manner that the centre ball bearing embraces the end of the crankshaft and the ratchet wheel engages with suitable stops attached thereto.

The engine starter is single-acting ; compressed air is admitted through a plate bolted over the valve mechanism and enters the various ports as they are uncovered by the slot in the rotating disc. From thence it passes up the channels in the castings to the cylinder heads. Exhaust is by means of ports which are uncovered when the pistons descend. The starting magneto (not shown) is driven in such a manner that adequate current is provided for firing purposes at the lowest speed. The geared-up shaft projects and is squared to take a handle, thus enabling the starter and engine shaft to be revolved by hand. Inv. 1919–429.

## AIRSCREWS

107. PROPELLER OF SANTOS-DUMONT DIRIGIBLE BALLOON. Presented by Messrs. Short Brothers.

This large propeller was designed by the Brazilian inventor and airman M. Santos-Dumont, and was used on his No. 6 Airship.

The propeller, which has a diameter of 13 ft., is built up of metal framework and is covered with a doped fabric. Inv. 1913–448.

108. MAXIM'S MODEL PROPELLERS. Lent by A. P. Thurston, Esq., D.Sc.

Before building his large experimental aeroplane, Sir Hiram Maxim experimented with small model propellers, in 1891, in order to determine the best shape to employ in his machine. Some of these small propellers are shown. The best three, as found by Maxim, are those marked A, B, and C respectively.

See Maxim, *Artificial and Natural Flight.* Inv. 1913–429, 1926–459/460.

109. AEROPLANE PROPELLER. Presented by Sir Hiram Maxim.

This large two-bladed propeller is one of the two designed by Sir Hiram Maxim for propelling his first flying machine, constructed in 1894.

The propeller, which is built up of several pieces of wood and is covered with a fine fabric, has a diameter of 17·83 ft. and a pitch of 16 ft. It was designed to absorb the power of a compound steam engine (see Cat. No. 4) which developed about 180 h.p. at 300 lb. per sq. in., and it actually produced a horizontal thrust of over 1,000 lb. Inv. 1896–98c.

110. HORATIO PHILLIPS' AIRSCREW, 1894. Presented by A. H. Phillips, Esq.

This laminated tractor airscrew was used by Mr. Horatio Phillips on the more powerful of his experimental aeroplanes designed in 1890–3.

Phillips, after more than 25 years of study and experiment, patented in 1884 (Spec. No. 13,768) the curved form of aerofoil embodying the form of dipping entering edge known as the "Phillips Entry," and applied these aerofoils in the form of long and narrow planes, mounted after the manner of a Venetian blind, to a steam-driven carriage which was arranged to run round a circular track, whilst being restrained by ties from a central mast, so that the machine could only rise vertically.

With this machine, patented in 1890 (Spec. No. 20,435), he was enabled, during May 1893 to lift 400 lb. for a distance round the track of nearly 2,000 ft., at a speed of 40 m.p.h., the loading on the planes being 2·5–3 lb. per sq. ft., an achievement which entitles Phillips to rank high among the pioneers of mechanical flight. A further form of curved aerofoil, of the "bull-nosed" type, was patented by him in 1891 (Spec. No. 13,311).

The diameter of the propeller shown is 5·6 ft., the maximum width of the blades being 2 ft. and the pitch about 4·5 ft. The blades are built up of laminations in the modern manner, stiffening stringers being fastened across the widest portion of the blades to avoid distortion when running.

The work of Phillips is dealt with fully in the following works :—O. Chanute, "Progress in Flying Machines," 1894, pp. 166–72 ; J. E. Hodgson, "The History of Aeronautics in Great Britain," 1924, p. 284 ; Twenty-Third Report of the Aeronautical Society of Great Britain, 1891–3, p. 65 ; and *Engineering*, 1893, Part I, pp. 288, 48, 653, and 714. Inv. 1926–628.

111. PROPELLERS FROM EARLY WRIGHT BIPLANE. Lent by the War Office.

These are two examples of an early propeller of the type designed by Wilbur and Orville Wright, and are similar to those used on the original Wright aeroplane in 1903.

These propellers—which were mounted in rear of the main planes on the Wright biplane—are cut from solid timber and are covered with a fine doped fabric. Inv. 1913–454

112. WRIGHT PROPELLER. Presented by Col. Alec Ogilvie. Inv. 1920–382.

113. WEISS TRACTOR AIRSCREW. Presented by A. Keith, Esq.

This tractor airscrew, which has been cut from a solid block of American white wood, was designed by José Weiss and is similar to that used on the Weiss monoplane in 1910.

José Weiss conducted experiments in order to determine the most suitable form for airscrew construction many years before he produced his first power-driven aeroplane. He was successful in designing a type of propeller very similar to that which is now universally employed.

The airscrew shown was designed to absorb the power of an eight-cylinder E.N.V. engine of about 30 h.p. Inv. 1921–358.

114. "NORMALE" TYPE PROPELLERS. Lent by the Dover Aviation Co., Ltd.

These six specimens illustrate the various stages in the manufacture of a type of square-bladed propeller used by the pioneers of flight. The method of construction is similar to that described in the adjacent exhibit of a tractor airscrew of the B.E.2 type.

The first specimen shows the four separated laminations of walnut arranged stepwise with twelve rivets in position.

The second specimen shows the laminations glued together and held tight by the rivets.

The third specimen shows the laminations cut away for final shaping, the rivets having been removed.

The fourth specimen illustrates the stage prior to sheathing. The wood has been shaped to the correct curvature and planed.

The fifth specimen shows the propeller with tips sheathed and ready for varnishing.

The sixth specimen shows the complete polished and varnished propeller.

Inv. 1913–574.

115. TRACTOR AIRSCREW, SHOWING METHOD OF CONSTRUCTION. Lent by the War Office.

Modern airscrews are built up of from four to eight separate laminations of walnut or mahogany, which are glued together stepwise. When set, the whole is pegged, and the sections at various points are worked out in accordance with the drawings, the remainder of the material being shaped in smooth curves to correspond. The four-bladed tractor airscrew shown illustrates this process.

The B.E.2 type tractor airscrew represented is constructed of five laminæ of walnut glued together. One blade is shown in this, the first stage of manufacture. The second blade shows the glued-up block pegged and cut away, being shaped into curves to agree with the sections at various points previously determined from drawings. The third blade illustrates the stage prior to varnishing. The shaping to final section was accomplished by hand, special attention being paid to the leading and trailing edges. The pitch angle and blade section was checked and the whole sand-papered and covered with a wood-filler. The fourth blade shows the airscrew in its finished state. The wood has been given two or three successive coats of copal varnish, being rubbed down after each coat with powdered pumice and a final coat of varnish applied.

Inv. 1913–456.

116. TRACTOR AIRSCREWS SHOWING METHOD OF CONSTRUCTION. Lent by the Imperial War Museum.

Modern airscrews are built up from separate laminæ of walnut or mahogany, which are glued together stepwise. When set, the whole is pegged, and the sections at various points are worked out in accordance with the drawings, the remainder of the material being shaped in smooth curves to correspond. The tractor airscrews shown illustrate this process.

(1) Shows a typical lamina.
(2) Shows the step-wise manner in which the laminæ are placed.
(3) Shows the laminæ glued together and under press.
(4) Shows one blade shaped into curves to agree with the sections at various points previously determined from the drawings.
(5) Illustrates the stage prior to varnishing, one blade being fabric covered. The shaping to final section was accomplished by hand, special attention being paid to the leading and trailing edges.
(6) Shows the airscrew in its finished state. The wood has been given two or three successive coats of varnish, being rubbed down after each coat with powdered pumice, and a final coat of varnish applied.

Inv. 1923–1354, and 1356/7/8/9/1360.

117. AIRSCREW GLUEING PRESS. Lent by the Imperial War Museum.

The processes of manufacture of laminated wooden airscrews are described in detail in an adjacent exhibit. The press illustrates the method of glueing up the laminations, packing blocks being used to distribute the pressure evenly over the whole of the glued surfaces. The laminated block is usually left in the press for a considerable time, generally 48 hours, to ensure even drying of the joints and the thorough setting of the glue. Inv. 1923–1360.

118. INTEGRAL PROPELLER. Lent by the Imperial War Museum.

Designed for a 50 h.p. Gnome engine. Rotation: clockwise. Laminæ of walnut. Inv. 1923–1399.

119. BLÉRIOT TRACTOR AIRSCREW. Lent by the Imperial War Museum.

Designed for a 50 h.p. Gnome engine. Rotation: anti-clockwise. Laminæ of mahogany. Inv. 1923–1453.

120. INTEGRAL TRACTOR AIRSCREW. Lent by the Imperial War Museum.

Fitted with a cowl for the purpose of diminishing head-resistance. Rotation: anti-clockwise. Laminæ of mahogany. Inv. 1923–1370.

121. INTEGRAL TRACTOR AIRSCREW. Lent by the Imperial War Museum.

Designed for an 80 h.p. Le Rhône engine, fitted to a Sopwith Scout. Rotation: anti-clockwise. Laminæ of mahogany tipped with fabric. Inv. 1923–1362.

122. LANG TRACTOR AIRSCREW. Lent by the Imperial War Museum.

Designed for a 110 h.p. Clerget engine. Rotation: anti-clockwise. Laminæ of mahogany. Inv. 1923–1400.

123. R.A.F. TRACTOR AIRSCREW. Lent by the Imperial War Museum.

Designed for a 150 h.p. Hispano-Suiza engine fitted to an S.E.5 biplane. Rotation: anti-clockwise. Laminæ of walnut. Inv. 1923–1391.

124. HEATON TRACTOR AIRSCREW. Lent by the Imperial War Museum.

Fitted to a B.E.12 aeroplane. Rotation: clockwise. Laminæ of teak. Fabric tipped. Inv. 1923–1386.

125. GERMANIA TRACTOR AIRSCREW. Lent by the Imperial War Museum.

Designed for a 200 h.p. Benz engine. Rotation: anti-clockwise. Laminæ of walnut and ash. Inv. 1923–1376.

126. AXIAL TRACTOR AIRSCREW. Lent by the Imperial War Museum.

Designed for a 110 h.p. Oberusel engine. Rotation: anti-clockwise. Laminæ of walnut, ash, and mahogany. Inv. 1923–1363.

127. WOTAN TRACTOR AIRSCREW. Lent by the Imperial War Museum.

Designed for a 200 h.p. Benz engine. Rotation: anti-clockwise. Laminæ of mahogany and ash. Inv. 1923–1387.

128. ASTRA PROPELLER. Lent by the Imperial War Museum.

Designed for a 200 h.p. Benz engine. Rotation: anti-clockwise. Laminæ of teak and ash. Inv. 1923–1385.

129. LANG TRACTOR AIRSCREW. Lent by the Imperial War Museum.

This is a clockwise tractor airscrew designed for a 225 h.p. Sunbeam engine. It is covered with fabric and is tipped with brass. Inv. 1923–1394.

130. FARRINGDON PROPELLER. Lent by the Imperial War Museum.

This is an anti-clockwise propeller designed for a 230 h.p. engine, and is covered with fabric. The diameter is 13·5 ft. Inv. 1923–1352.

131. INTEGRAL TRACTOR AIRSCREW. Lent by the Imperial War Museum.

Fitted to a Morane Bullet aeroplane. Rotation: anti-clockwise. Laminæ of mahogany. Inv. 1923–1404.

132. PARAGON TRACTOR AIRSCREW. Lent by the Imperial War Museum.

Designed for experimental purposes. Rotation: anti-clockwise. Laminæ of ash and pine. Inv. 1923–1380.

133. ODDY TRACTOR AIRSCREW. Lent by the Imperial War Museum.

Designed for a 250 h.p. Rolls-Royce engine. Rotation: anti-clockwise. Laminæ of mahogany, fabric covered. Inv. 1923–1395.

134. INTEGRAL TRACTOR AIRSCREW. Lent by the Imperial War Museum.

This is a right-handed four-bladed tractor airscrew, arranged for use on a 100 h.p. Anzani engine.

The material used is walnut, and the blades have small brass tippings to protect the edges from damage when landing in long grass, or, when used for a float seaplane, against the destructive action of the spray when taxying. Inv. 1923–1414.

135. INTEGRAL TRACTOR AIRSCREW. Lent by the Imperial War Museum.

Designed for a 70 h.p. Renault engine. Rotation: clockwise. Laminæ of walnut. Inv. 1923–1415.

136. VICKERS TRACTOR AIRSCREW. Lent by the Imperial War Museum.

Fitted to a B.E. aeroplane. Rotation: anti-clockwise. Laminæ of mahogany. Inv. 1923–1413.

137. INTEGRAL TRACTOR AIRSCREW. Lent by the Imperial War Museum.

Designed for a 100 h.p. R.A.F. engine fitted to a B.E.2C biplane. Rotation: clockwise. Laminæ of walnut. Inv. 1923–1416.

138. AIRSHIP PROPELLER. Lent by the Air Ministry.

This is one of the two propellers mounted on H.M.A. No. 2. Rotation: clockwise. Laminæ of walnut and ash. Fabric tipped. Inv. 1921–83.

139. TRACTOR AIRSCREW. Presented by the Aircraft Manufacturing Co., Ltd.

Designed for a F.I.A.T. engine fitted to a D.H.9 biplane. Rotation: anti-clockwise. Laminæ of mahogany. Fabric tipped. Inv. 1920–592.

140. THREE FOUR-BLADED TRACTOR AIRSCREWS. Presented by the Aircraft Manufacturing Company, Ltd.

(*a*) This is a right-hand tractor airscrew, designed for a D.H.4 aeroplane, to be fitted to a 250 h.p. Rolls-Royce "Falcon" engine, Mark III. Diameter, 8·75 ft.

(*b*) This is a similar, but left-hand, tractor airscrew.

(*c*) This is a left-hand tractor airscrew, designed for a D.H.4 aeroplane, to be fitted to a 250 h.p. Rolls-Royce "Falcon" engine. Diameter, 8·75 ft. The material in all cases is mahogany. Inv. 1920–592.

141. LANG TRACTOR AIRSCREW. Lent by the Imperial War Museum.

This four-bladed airscrew was designed for an airship, but was never used. Rotation: clockwise. Laminæ of mahogany and sycamore, fabric covered. Inv. 1923–1396.

142. SMALL LANG PROPELLER. Lent by the Imperial War Museum.

This example of a small tractor airscrew was designed in 1917 primarily for use on an A.B.C. "Gnat" engine of 28–30 h.p., mounted in a R.E. experimental machine for control by wireless waves.

The same design of airscrew was used for the small "Kitten" type aeroplanes, designed at Eastchurch Air Station and the Isle of Grain Experimental Station during 1917.

See Jane, *All the World's Aircraft*, 1920. Inv. 1923–1369.

143. MODEL OF B.E.2C FOUR-BLADED TRACTOR AIRSCREW. Lent by the War Office.

This screw was designed at the Royal Aircraft Factory, Farnborough, in 1913. The speed of the aeroplane was about 70 m.p.h., and the engine an 80 h.p. Renault. Inv. 1913–456.

144. EXPERIMENTAL COCHRANE METAL PROPELLER. Lent by the Royal Aeronautical Society.

This type of propeller has been experimented with both in model and full-scale form. Claims were made for the corrugated surfaces, it being supposed that the corrugations reduced slip on the face. Nothing was known at that period of the theory of in-flow. Inv. 1919–558.

145. ARMOURED PROPELLER. Lent by the Integral Propeller Co., Ltd.

This propeller has been fitted with a sheathing of Naval Brass in order to render it, to some extent, proof against machine-gun fire and other projectiles. The metal

covering is designed to deflect projectiles and to prevent thereby any penetration and consequent damage to the propeller.

The metal sheathing has been set flush with the blade and riveted at regular intervals over its whole area. The rivets have been applied alternately from face and back, headed and filed to form a smooth surface.

The whole sheathing was subsequently machined in order to give it the correct shape. Inv. 1920–448.

146. EXPERIMENTAL METAL AIRSCREW. Presented by the Metal Airscrew Co., Ltd.

This is an example of an all-metal rigid airscrew designed by Mr. Henry Leitner in 1917. The airscrew is constructed of sheet steel, being hollow from boss to tip. A portion of the metal has been cut away in order to show an internal web which serves to strengthen and maintain the shape of the shell. Inv. 1922–470.

147. LEITNER-WATTS METAL AIRSCREW. Presented by the Metal Airscrew Co., Ltd.

This is an example of an all-metal airscrew patented by Mr. Henry Leitner and Mr. Henry C. Watts. The blades, which are made of sheet steel, are adjustable through a wide range of pitch to suit any individual engine or aeroplane.

Each blade is made up in the form of a shell and the necessary taper is obtained by using laminated construction, which construction also tends to damp out vibration. The two halves of each blade are attached to one another, at the edges, by welding. In order to stiffen the shell thus formed, a seam is introduced in the face and struts are inserted between it and the back of the shell.

The hub socket is made from a steel forging. It consists of two pieces held together by bolts and designed to embrace the two blade roots. The blade settings are recorded by means of a protractor on the hub socket and a datum line on the hub root. Hub bushes are made to fit the shafts of various engines ; externally they are castellated to mesh with the internal castellations of the hub socket. The hub bush is held on the engine shaft by a loose cone and cone nut which is locked by a single locking plate. The L.W. metal airscrew compares favourably with a wooden airscrew as regards weight and is unaffected by climatic changes. It is claimed that the airscrew is free from distortion and that if struck by a projectile the damage is local. Inv. 1922–471.

148. SECTION OF SHEET STEEL AIRSCREW BLADE ROOT. Presented by the Metal Airscrew Co., Ltd.

This section shows the arrangement of the laminæ at the root on the first type of Leitner-Watts detachable-bladed metal airscrew.

The laminated blade sheets have been fitted between an inner and outer sleeve, being subsequently riveted and sweated. The bottom clamping plates were afterwards fixed in position. Inv. 1922–472.

149. SECTIONED BLADE ROOT OF LEITNER-WATTS AIRSCREW. Presented by the Metal Airscrew Co., Ltd.

This section shows the arrangement of the laminæ at the root of the blade in the Leitner-Watts metal airscrew, an example of which is exhibited adjacently.

The blade root or butt is constructed in such a manner as to obviate the danger of its being torn out of the hub socket even under the stresses arising at extreme peripherial speeds. The blade laminæ are riveted and welded to a flanged sleeve which is gripped by the hub socket. They are also welded to an internal welding ring, a solid mass being formed at their extremities by a V-shaped weld. Inv. 1922–473.

150. FAIREY-REED METAL AIRSCREW, 1920. Presented by Messrs. the Fairey Aviation Co., Ltd.

This is a development of the metal airscrew patented in U.S.A. by Mr. S. A. Reed in 1920, and in Great Britain in 1922 (Specn. No. 163,714), the manufacture in Great Britain being carried out by the donors.

The system of construction makes use of a plate of aluminium or duralumin which is widest and thickest at the central portion where the plate is so formed or bent that the entering edge of one blade becomes the trailing edge of the other. From the centre the plate is tapered both in width and thickness to the tips. The centre portion is gripped between formed half bosses which provide a solid gripping bed for the bent centre of the plate and also a means of attachment to the driving shaft.

The sections of the blade from the root to the tip are so proportioned that the ratio of rigidity to flexibility is such that the outer and thinner portions of the blade depend mainly upon centrifugal force due to the mass of the blades themselves to give the necessary rigidity in operation, although these outer portions and the tips are relatively flexible in themselves.

The Fairey-Reed airscrew is now widely used on service and commercial aircraft and has been fitted to practically all the winning racing aeroplanes and seaplanes of recent years. The small example shown was made in 1922 for use with an A.B.C. "Scorpion" engine developing 34–40 h.p. at 2,300–2,750 r.p.m., and fitted in a Westland "Woodpigeon" light aeroplane. Inv. 1927–192.

151. EXPERIMENTAL VARIABLE PITCH AIRSCREW. Lent by W. R. Turnbull, Esq.

This airscrew was designed by Mr. W. R. Turnbull with the object of providing a propeller the pitch of which could be varied at will during flight It is stated to be the first propeller used on an aeroplane with the regulation of pitch under full control. It is claimed that, under test, the rate of climb and the absolute ceiling of the aircraft were considerably increased.

The airscrew, which is designed for a 130 h.p. Clerget engine, is constructed of mahogany, bronze, and nickel chrome steel, and weighs 90 lb. The pitch is altered by a small electric motor mounted at the centre of the boss and operating the blades through gearing. The motor, which is reversible, is controlled from the cockpit by means of a reversing switch. The airscrew was tested on an Avro biplane by Officers of the Canadian Air Force during June and July 1927, when the improved performances mentioned above were noted. The invention has been patented in the United States of America. Inv. 1929–4.

# BIBLIOGRAPHICAL REFERENCES

A small selection of the more important books and technical journals in the Science Museum Library, dealing with the history, research, and constructional practice of internal combustion engines and airscrews for the propulsion of aircraft.

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ADVISORY COMMITTEE FOR AERONAUTICS. Reports. 1910–21.
*Continued as*

AIR MINISTRY. Reports of the Aeronautical Research Committee, 1921 onward. (The series of reports and memoranda, consisting of between 700 and 800 publications, will furnish the advanced student with a survey of research carried out on engine design and testing procedure.)

AIR MINISTRY. Technical Publications. (These deal with advanced research and technical problems.)

BOILEAU, CH. Le moteur à essence adapté à l'automobile et à l'aviation. 1918.

BREWER, R. W. A. The Art of Aviation. 1910.

BURLS, G. A. Aero Engines. 1915.

CHANUTE, OCTAVE. Progress in Flying Machines. 1894.

FAGE, A. Airscrews in Theory and Experiment. 1920.

GANDILLOT, MAURICE. Abrégé sur l'hélice et la résistance de l'air. 1912.

GRAFFIGNY, H. DE. Les moteurs légers, applicables à l'Aéronautique, à l'Aviation, etc. 1899.

HARGRAVE, LAWRENCE. Papers read before the Royal Society of New South Wales.

HAYWARD, C. B. Practical Aeronautics. 1912.

HODGSON, J. E. The History of Aeronautics in Great Britain. 1924.

HUTH, DR. FRITZ. Luftfahrzeugbau. 1909. 1910.

JANE, F. All the World's Aircraft, 1909–10 onward, annually.

JUDGE, A. W. Handbook of Modern Aeronautics. 1919.

KEAN, F. J. Aeronautical Engines. 1916.

LANCHESTER, F. W. The Flying Machine from an Engineering Standpoint. 1915.

LANGLEY, S. P. Langley Memoir of Mechanical Flight. Vols. I and II. 1911. Issued by the Smithsonian Institution.

MANUAL, THE AERO. 1910.

MARKS, L. S. The Airplane Engine. 1922.

MAXIM, SIR H. S. Artificial and Natural Flight. 1909.

MORGAN, J. D. Principles of Electric Spark Ignition in I.C. Engines. 1920.

PAGÉ, V. M. Aviation Engines. 1919.

PAGÉ, V. M. Gasolene and Kerosene Carburetters. 1919.

PARK, W. E. A Treatise on Airscrews. 1920.

PATENTS—
- Index of Subject Matter, Abridgments, and Printed Specifications for British Patents in Aeronautics, and Engines, Internal Combustion.
- Germany. Kaiserliche Patentamt. Collected Specifications.
- U.S.A. Patent Office. Collected Specifications.

PERIODICALS—
- Aéro, L'.
- Aero, The. 1908 onward.
- Aeronautics.
- Aéronautique, L'.
- Aérophile, L'.
- Aeroplane, The.
- Air, L'.

Aircraft Engineering. Technical journal.
Automobile Engineer, The. A technical journal devoting a portion of its space to aeronautical engine design problems.
Automotor Journal. To 1908. This was issued as a separate paper from January 1909, and known as FLIGHT.

Aviation.
Engineering. Periodical articles and descriptive matter dealing with aeronautical engineering matters.
Engineer, The. Ditto.
Flight. 1909 onward.

RATEAU, A. C. E. Théorie des hélices propulsives marines et aériennes, etc. 1920.

RIACH, M. A. S. Airscrews. 1916.

RIACH, M. A. S. The Screw Propeller in Air. 1917.

SMITHSONIAN INSTITUTION, WASHINGTON. Langley Aerodynamics Laboratory. Reports. (These constitute the same source of advanced technical information as the Reports of the British Advisory Committee and the Aeronautical Research Committee.)

SOCIESTÀ IDROVOLANTI ALTA ITALIA. The Pistolesi variable pitch aeroplane propeller. 1925.

STRINGFELLOW, F. J. A Few Remarks on what has been done with Screw-Propelled Aeroplane Machines. 1809–92.

STRINGFELLOW, J. Aeronautical Classics, No. 5. Issued by the Royal Aeronautical Society.

TOEPEL, M. E. Automotive Magneto Ignition. 1919.

WATTS, H. C. The Design of Screw Propellers. 1920.

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